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Post-Harvest Storage Studies With Selected Fruits

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POST-HARVEST STORAGE STUDIES WITH SELECTED FRUITS

by

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INTRODUCTION

It has been estimated that one-fourth of the fresh fruits harvested are never consumed because of spoilage. This spoilage amounts to many thousands of tons of fruits which are valued annually at several million dollars. Several factors are responsible for the post-harvest spoilage of fruits, namely, pathological, physiological, and mechanical.

Men in the past have used various methods to control pathological spoilage of foods. The recent development of nuclear radiation, antibiotics, fungicides, and packaging films provides new methods for prolonging the shelf-life of many fruits. These may prove important in countries like India where refrigeration facilities are not readily available and food shortage has always been a problem. Likewise, in the United States, the present-day marketing of fresh fruits has become more and more complex because centers of consumption are increasingly remote from centers of production.

To understand physiological and mechanical spoilage of fruits one should know that perishable products are alive, even though the connection with the source of nourishment has been severed. Continued metabolism and increase in respiration result in over-ripeness, physiological decay, and wilting. The deterioration of fruits by the processes of accelerated respiration induced by ripening, physical changes, and subsequent mechanical damage during transit cannot be stopped; but it can be retarded by lowering the temperature, by treating with respiratory inhibitors, and by careful handling.

The objectives of the research presented herein are: (1) to study

the effects of selected fungicides, antibiotics, beta and gamma radiations, and packaging films on respiration, control of fungal deterioration, and subsequent refrigeration life of apricots, peaches, and pears; and (2) to study (*in vitro*) fungi responsible for deterioration of these fruits and to determine whether they are susceptible or resistant to selected chemicals and to ionizing radiations.

REVIEW OF LITERATURE

The following publications reporting the investigations of chemical, packaging, and ionizing irradiation effects on respiratory behavior, disease control, and maintenance of quality of certain fruits and vegetables have been reviewed as a background for this study.

Chemical Effects

Emmert and Southwick (1954) reported in a preliminary study that 2,4-D had little effect and napthaleneacetic acid had no effect on the respiration of mature green tomatoes. Woodruff and Crandall (1958) studied 18 respiratory inhibitors on apples. They reported that Na-malonate (0.001 M), 3-indolepropionic acid (0.0005 M), hippuric acid (0.0005 M), and benzimidazole (0.001 M and 0.0005 M) were the most effective materials in reducing the respiratory rates.

Denny (1924) reported that ethylene at concentrations 0.1, 0.01, 0.001, and 0.0001 percent increased the respiration of green lemons. The effect appeared to be greatest at the intermediate concentrations. The increase in CO_2 production ranged from about 100 percent to about 250 percent. In contrast to this, Eaks (1959) found that ammonia fumigation had no effect on the respiratory rate, the chemical composition of the juice, and the general appearance of oranges. Biale and Shepherd (1941) reported that gaseous products of moldy lemons inoculated with Penicillium digitatum caused a marked increase in the rate of CO_2 evolution and accelerated color development of round green lemons.

Maxie et al. (1958) studied the effect of various oxygen concentrations on respiration and ripening in Wickson plum at 68° F. High oxygen concentrations were found to induce a climacteric rise in plums, but a high oxygen treatment did not affect respiration when the climacteric was induced with ethylene before the treatments were applied to the fruit.

Biale (1946) reported that when the oxygen concentration surrounding Fuerte avocado fruit was reduced to the values below that of air, the rate of carbon dioxide evolution was markedly influenced with the climacteric peak being delayed and suppressed in magnitude. At an oxygen tension higher than air no significant differences were noted.

Gustafson (1930) deprived tomato fruits of all ages and stages of development of oxygen by substituting nitrogen or hydrogen and usually noted a subsequent increase in carbon dioxide production. When air was introduced, there was always an increase in carbon dioxide production. He suggested that respiratory substances were formed during the intramolecular phase which were rapidly oxidized to carbon dioxide and water when air was again admitted. Later Gustafson (1936) reported that when tomatoes were exposed to conditions in which the oxygen tension decreased while the carbon dioxide tension increased, there was a concentration at which the respiratory activities were decreased. The amount of decrease was associated with the stage of development of the fruits. He further stated that normally the oxygen consumption was somewhat greater than the CO_2 production, yet there was an oxygen and carbon dioxide tension at which less oxygen was consumed than carbon dioxide produced. This might be due to the anaerobic respiration.

Platenius (1943) studied five vegetables: asparagus, snap beans,

shelled peas, and carrots, which were held in respiration chambers in which part of the oxygen was replaced by nitrogen. He reported that the critical oxygen concentrations below which the tissue was injured by anaerobic respiration were about 1 percent for spinach and snap beans, 2.5 percent for asparagus, and 4 percent for peas and carrots, when held for several days at 68° F. By choosing the most effective oxygen concentration, the respiration rate could be reduced about 50 percent. Likewise, Choudhury (1939) studied changes in the respiration intensities of the tubers of potatoes and artichoke and the roots of carrots under a wide range of oxygen concentrations for several days at 77° F. He found that in potatoes the normal respiratory activity was maintained in different oxygen concentrations ranging between 6.2 and 98.6 percent; but when the oxygen concentration was above that in air, there was no change in the normal course. On carrots the respiration rate altered with every rise in oxygen concentration.

Claypool and Allen (1951) reported that Wickson plums held at 77° F attained earliest and highest respiration peaks and ripened at faster rates than did fruits held at any other temperatures. It was also reported that fruits held in oxygen levels above that in air were accelerated both in ripening and respiration rates and it was thought that abnormal ripening and loss of vitality of fruits at 86° and 95° F resulted from influences of high temperature upon the enzyme systems, in addition to the oxygen effect. Tewfik and Scott (1954) reported the CO_2 production of tomatoes, lima beans, snap beans, sweet corn, peas, and asparagus over a 7-day storage period at temperatures of 32°, 38°, 44°, and 72° F. They stated that carbon dioxide production increased rapidly with rise in temperature; the rate at 44° F was approximately

double that at 32° F for sweet corn, lima beans, and peas.

Lyons and Rappaport (1959) reported initial respiration rates of Brussels sprouts which ranged from 38 mg. CO_2/Kg./hr. at 32° F to 190 mg. CO_2/ Kg./hr. at 68° F. They further pointed out that Brussels sprouts deteriorated rapidly at temperatures above 50° F but maintained acceptable quality for long periods at temperatures below 50° F. Likewise, Lipton (1957) stated that in the range of 86° F initial and average rates of respiration of asparagus were higher at the more elevated temperatures. He reported initial ranges from 60 mg. CO_2/Kg./hr. at 32° F to about 900 at 86° F.

Smock (1944) reported that the respiratory rate of a given lot of fruit in storage depended upon its age, climate during the growing season, temperature, CO_2 and O_2 levels, and ethylene concentration. Ting (1952) suggested that during the period between 140 days (1st picking) and 175 days (last picking) there was a general, slow increase in the respiration rate, an increase in reducing sugars and non-reducing sugars, and a decrease in total alcohol insoluble solids and firmness of the fruits of Rome Beauty apples. Bose and Basu (1954) reported that the respiration intensity at 37° F for Fajli mangoes coated by (a) dipping in paraffin bath at 80° F for 10 seconds and (b) dipping in a 50 percent solution of paraffin in petroleum ether for 10 seconds was 2.2 and 8.04 mg. of CO_2/Kg./hr. as compared to 9.70 for untreated mangoes.

Brooks (1938) suggested that the skin of the harvested tomato was practically impermeable to gases, and the connection of internal atmosphere with the external was only through the stem scar. Beedle (1937) studied the relationship between the growth rate, respiratory

intensity, and carbohydrate content of tomato fruit; and stated that the fruits which ripened first had the highest sugar content and the highest respiratory intensity, and occupied the first position on the truss.

Gustafson (1929) reported that there was a decrease in the production of CO_2 by John Baer tomato fruit during growth until a point of minimum production was reached at about the time the increase in size stops; this was followed by an increase in CO_2 production which reached its maximum when the fruits were orange to red in color and that thereafter there was a final decrease in the rate of respiration. Singh and Mathur (1939) suggested that the respiration curve during the growth of the fruits showed two high values separated in time; one was initial and represented a high rate of respiration in young fruits, while the other occurred at the onset of the senescence.

Jones (1942) reported that ripening changes, especially sucrose changes of papaya fruit, were retarded by all temperatures (40°, 45°, 50°, 55°, and 60° F). It was suggested that in the transport and marketing of papayas the temperature should not be allowed to go below 50° F. Likewise, Allen (1953) observed the fruit ripening and respiration rates for different lots of Bartlett pears harvested from trees sprayed with several hormones. He mentioned that the general effect of these spray materials was to accelerate ripening and respiratory behavior.

Biale (1950) explained the climacteric rise in respiration as the critical state which separated the stages of development and maturation from the stage of functional breakdown. The climacteric denotes the beginning of the end. Any treatment or condition which delays the onset of the climacteric also delays senescence.

Hulme (1954) reported that in the respiration of apples, the difference in time between the onset of the climacteric at 53.6° F and at 59.0° F was shown to vary with the date of picking, and that this "time gap" had a minimal value which may vary from season to season. He further pointed out that this possibility may prove to be a guide to "absolute" maturity in relation to picking for maximum storage life. Millerd, Bonner, and Biale (1953) studied the climacteric rise in respiration of ripening avocado fruits. The active respiratory particles (similar to mitochondria) were isolated from both preclimacteric and climacteric fruits. Workman, Pratt, and Morris (1957) reported that mature-green, freshly harvested tomatoes held at 68.0° F showed the respiration pattern of climacteric peak expected in fleshy fruits.

Hansen (1942) found that in fruits in air at 58.0° F the rate of ethylene production increased during the climacteric rise in respiration, reached a peak at the respiratory climax, then declined during the post climacteric period. Likewise, Gane (1937) reported that ethylene was a normal product of metabolism during the climacteric when it acted as an autocatalyst and produced ripening effect similar to 1 ppm ethylene. Hansen (1943) reported that immature pears which were producing ehtylene in amounts that could be detected only by a sensitive biological method did not ripen if the emanations formed by the fruit were removed from the storage atmosphere; on the other hand, if emanations were allowed to accumulate or if synthetic ethylene was incorporated in the atmosphere, both respiration and ripening were stimulated.

Biale et al. (1954) reported that the ratio of ethylene evolution

to CO_2 output was the highest for apples, followed by sapote, pear, cherimoya, peaches, papaya, feijoa, avocado, persimmon, and banana; however, oranges and lemons exhibited no climacteric and produced no ethylene. Ernest et al. (1957) reported that onset of ethylene production coincided with the onset of the climacteric rise, but the peak of ethylene production was reached 2 days after the climacteric peak was attained at 68° F and 8 days after it was reached at 77° F. Likewise, Workman and Pratt (1957) established the pattern of ethylene production by tomato fruit in relation to respiration and rate of ripening; the plot of the rate of ethylene evolution with time was found to be that of a sigmoid curve.

Workman et al. (1957) reported that field chilling injury before harvest did not affect the normal respiratory pattern of mature green tomatoes, although pre-harvest chilling affected the rate of ripening and market quality of ripened fruit.

Nelson (1926) reported that black leaf speck of crucifers, red heart of lettuce and cabbage, and surface pitting of potato tubers were the symptoms of breakdown under present conditions of storage and transportation and were caused primarily by an inadequate supply of oxygen or by temperatures which prevent the utilization of the oxygen present. Huber (1932) suggested that 124 species of fungi belonging to 29 genera, not including 23 unclassified, non-rot producing forms, could be isolated from the surface of normal apples. Likewise, Nelson (1933) reported the symptoms of storage spot or pox disease of citrus fruits under conditions of poor ventilation or where the temperature was so low that normal respiratory functions were deranged. Cheema, Karmarker, and Joshi (1950) reported that mature green mango with high acidity were resistant to decay caused by Gloesporium

mangiferae as compared to yellow ripe fruit with low acidity.

Narasimham, Bedford, and Robertson (1954) reported that although there were varietal differences, the shiny black raspberries always had the lowest mold count and were, therefore, the most suitable for processing purposes.

Claypool (1953) reported that the spoilage of horticultural crops during the marketing period could be reduced by lowering the temperature, the use of germicidal dips, and other treatments.

Vandemark and Sharvelle (1952) suggested that the volatile chemical, trichloro-ethylene, prevented all breakdown of the inoculated peaches and plums and was effective at a concentration as low as 1:1000.

Akamine and Arisumi (1953) suggested that on papaya, among various treatments tried, only hot water treatment prior to fumigation with ethylene di-bromide materially reduced rot incidence. Likewise, Uota (1957) reported that the modified atmosphere alone did not control decay of Emperor grapes; whereas when 500 ppm of SO_2 was added weekly to the sealed chambers, the decay was reduced below the commercially acceptable level.

Waksman et al. (1952) reported that antibiotics comprised two groups of substances: (a) those which were active against bacteria, actinomycetes, and fungi, and (2) those which were active against fungi but not against bacteria or actinomycetes. Ayre and Denisen (1958) suggested that strawberries and black and red berries dipped in solutions containing Myprozine had lower microbial counts after storage than did the controls; the trials with other antifungals showed that Candidin, Ascosin, and Nyastatin at 10 mg. per ml. were stimulatory to

mold and yeast development. Likewise, Muller (1958) reported that Streptomycin and Neomycin had no influence on fungi; Eulicin, Candicidin, Mycostatin, Filipin, Amphotericin-B, and Candidin were effective against many fungi but not against bacteria; and Thiolutin was both antibacterial and antifungal.

DiMarco (1959) reported that out of 15 chemicals at different concentrations tested, 6 showed promise of controlling post-harvest decays of strawberries and peaches; the most effective chemicals were Captan, Dithane, Dowicide-A, Mycostatin, and sorbic acid. Likewise Almandil (1960) reported that among the antibiotics and fungicides tested on Aspergillus niger, Penicillium, Rhizopus, and yeast in vitro, Captan and Mycostatin were the most effective inhibitors for the organisms. Luvisi (1960) also suggested that dehydroacetic acid at 1 percent, sodium ortho-phenylphenate at 0.1 and 0.2 percent concentrations reduced post-harvest infections of peaches and nectarines to a very low level.

O'Reilly (1947) reported that peaches remained in good condition for longer periods of time when stored at 32° F and lower levels of CO_2 than at 40° F and 10 percent CO_2 level. Gerhardt and Ryall (1939) reported that cherries (vars. Bing and Lambert) could be held in CO_2 without impairment of flavor as follows: at 60° F for 12 days in 40 percent CO_2 concentration; at 45° F for 20 days in 40 percent; at 45° F for 17 days in 25 percent (also Napoleon); at 32° F for 31 days in 10 percent. They further stated that fungus decay of sweet cherries was controlled during 17 to 20 days storage at 45° F in 25 percent CO_2.

Wright (1940) reported that if maximum quality of tomatoes in flavor and color was desired, a temperature close to 60° F was

recommended; at this temperature the product was firmer, kept longer, and developed less decay than if ripened at higher temperatures.

Hansen (1951) reported that the vegetables held on ice-bed racks were generally in better condition longer than those held on other types of display racks. They explained that it might be due to the fact that low temperature held diseases to a minimum and the moisture kept the produce in a relatively turgid condition. Likewise, Holmes (1951) suggested that the storage life of squashes retaining their peduncles during the storage period was 50 percent longer than those without peduncles.

Hall et al. (1953) reported that apples picked at their optimum stage of maturity for cool storage held best after coating with 8 to 10 percent alcoholic solution of 2 parts castor oil to 1 part wax-free shellac; those picked either before or after this stage developed storage disorders. Likewise, Parsons and Wright (1956), while determining the effect of temperature, trimming, and packaging methods on lettuce deterioration, reported that after 6 weeks at 32° F, 55 to 67 percent of the untrimmed lettuce remained edible as compared with 26 to 57 percent at 38° F.

Packaging Effects

Smock and Van Doren (1941) reported that the storage life of apples was markedly increased by use of proper atmosphere and temperature.

Smock (1942) observed that McIntosh apples respired approximately one-third as fast in controlled atmosphere storage at 40° F as in ordinary cold storage at 32° F. Siegelman and Gerhardt (1953) reported the effect of temperature and wrapping films on the shelf life of

apricots. They suggested that all films (cellophane, 300 LSAT, polyethylene 150, and pliofilm 8FM) were suitable at 40° F but immediate venting was necessary upon transfer to higher temperatures. For this reason perforated bags were recommended for packaging.

Carolus and Lipton (1953) reported that asparagus when stored in film bags at the low temperature (35° to 37° F) was free from objectionable odors, darkening, or decomposition, and maintained acceptable edible quality during a continuation of the storage period up to 10 to 14 days. Kagan (1954) suggested that the use of synthetic resins for sealing packages in the food packing plants would provide greater cleanliness than the commonly used vegetable glues (susceptible to fungi).

Ryall and Uota (1955) reported that when apples were packaged in polyethylene (150 gauge) liners, the CO_2 and O_2 levels varied with the storage temperatures. They further stated that apples in the same polyethylene (150 gauge) liners at 40° F remained greener in color, firmer in texture, and developed less scald than those stored at the same temperature in the lighter (100 gauge) film liners or those stored without film liners. Boyer (1955) stated that though polyethylene box liners retarded the ripening of fruits, they aggravated such storage disorders as gel-breakdown in apricots, woolliness in peaches, and internal breakdown in plums. Therefore, he did not recommend box liners for wrapping stone fruits such as apricots, peaches, and plums.

Ayer and Denisen (1958) suggested that the use of plastic containers generally resulted in less spoilage of strawberries and raspberries than when the fruits were stored in wooden berry boxes, especially if the wood boxes had been used previously. Salunkhe et al. (1959) reported that the success of the preservation of irradiated

fresh fruits will depend upon the availability of semipermeable films which will allow normal respiration of the product and at the same time prohibit the entry of microbes. They further stated that aeration during irradiation of fruits and vegetables was essential to extend the shelf life as well as to retain the natural flavor of fresh fruits and vegetables by supplying O_2 for the normal respiration process and at the same time by removing CO_2 and other gases given out as a result of respiration and radiation.

Ionizing Radiation Effects

It would seem appropriate to review certain terms and definitions pertaining to ionizing radiations prior to discussion on its effects.

The term "ionizing" means the production of a positive ion by the ejection of an electron from the tissues through which the radiation particles traverse; the electron which is ejected eventually becomes attached to another atom and makes it a negative ion, and thus, the process by which the ions are produced is called ionization. Therefore, the radiation which produces ions by the above process is known as "ionizing radiation."

The ionizing rays from radioactive elements have been found to be of three kinds, namely, alpha, beta, and gamma. An alpha ray is a particle with the nucleus of the helium atom. Hence it is a positively charged nucleus. A sheet of paper can stop it. The use of it in food preservation is, therefore, not feasible. The beta particle is a negatively charged electron. It has a little more penetrating power than the alpha particle. Beta radiation could be utilized successfully in the surface pasteurization of many foods. Gamma radiation is a non corpuscular electro-magnetic radiation of extremely short wave length.

It is similar to X-ray and is a highly penetrating ray. Hence, it has tremendous possibilities in pasteurization as well as in sterilization of foods. The relationship of various types of radiation in the electromagnetic spectrum is shown in Figure 1. Beta and gamma radiations have shown promise in eliminating insect infestations, inhibiting the sprouting of tubers, bulbs, and roots, and in destroying the microbial population on many foods. The destructive characteristics of radiations for various substances are shown in Figure 2.

In order to express radiation exposure in quantitative terms, it is necessary to describe certain units. The most popular ones are roentgen (r), roentgen equivalent physical (rep), and rad. The roentgen (r) is the quantity of radiation which produces one electrostatic unit of positive or negative charge per cubic centimeter of dry air at standard pressure and temperature (Glasstone, 1958). The unit which would describe the absorption of energy in media other than air, the rep, was originally established as 83 ergs[1] per gram of a biological material. This unit is equal to the energy absorbed in air in a field of one roentgen. However, it was later found that one roentgen of moderate energy photons[2] results in the absorption of 93 ergs per gram of tissue in order to achieve equivalence with the roentgen in that medium. However, to eliminate confusion in the use of radiation sources the International Commission on Radiological Units recommended the use of rad, which does not refer to a specific medium. The rad is defined as the absorption of 100 ergs per gram of substrate.

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[1]Erg is a unit of energy of suitable magnitude for dealing with energy changes in single atoms or molecules; 1.602×10^{-12} erg = 1 electron volt.

[2]Quantum of radiant energy.

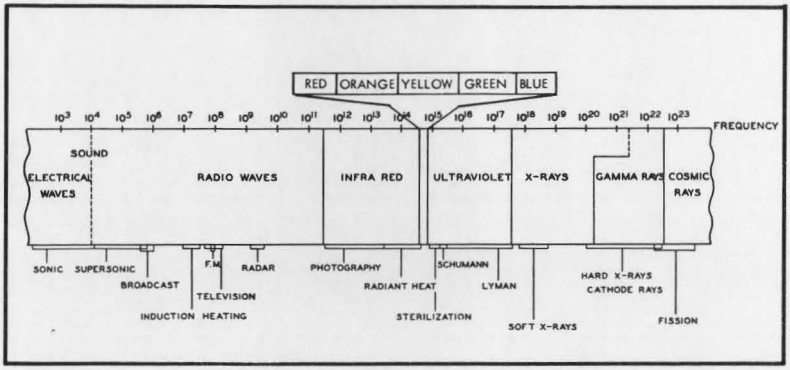

Figure 1. Relationship of various types of radiations in the electromagnetic spectrum.

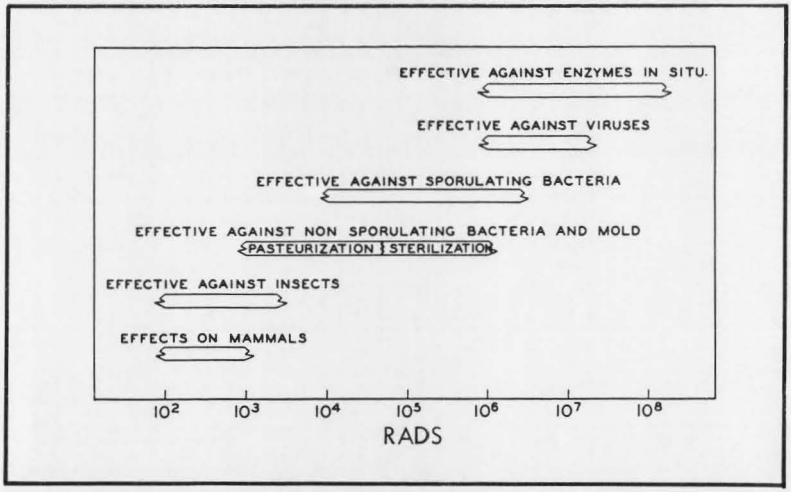

Figure 2. Lethal doses of ionizing radiation on mammals, insects, bacteria, fungi, viruses, and enzymes.

Burns (1959) reported that the respiratory pattern of mature green tomato fruit immediately exhibited a severe increase proportional to the amount of radiation dose applied; this increase of CO_2 evolved appeared to be related to the activation of substrate available to respiratory enzymes. Similarly, Salunkhe et al. (1959) reported that the oxygen uptake of the irradiated products was directly related to the radiation dose. Likewise, Desrosier (1959) was also of the same opinion and stated that respiration increased with the increased dose of ionizing radiation.

Beraha et al. (1955) reported that in grapes irradiated at 5×10^5 and 1×10^6 rep no rot developed in any of the replicates for a period of 10 days at room temperature while non-irradiated controls were completely rotted within four days. Similarly, Beraha et al. (1959, 1960) reported that 3×10^4 and 1×10^6 rads inhibited the fungal growth in vitro; also in vivo artificially inoculated peaches kept at 80° to 85° F were free of Rhizopus rot for 10 days after the dose of about $2\frac{1}{2} \times 10^5$ rep, whereas unirradiated peaches were completely rotted within 5 days. On the other hand, Beraha et al. (1959) stated that doses of gamma radiation ranging from 2×10^4 to 5×10^5 rads failed to prevent decay in potatoes inoculated with E. Carotovora.

Hannan (1954) reported that radiation doses of the order of 2×10^6 rep were required for the elimination of bacterial spores, 1×10^6 rep for yeasts and molds, and 5×10^5 rep for vegetative organisms, and about 5×10^4 rep for insects. McArdle et al. (1957) reported that radiation at $1\frac{1}{2} \times 10^5$ rep was most effective in reducing 95 percent of the brown rot of peaches. Asselbergs et al. (1958) suggested that apple juice irradiated at 6×10^5 rep or lower did not produce sterile

juice, but juice irradiated at 5×10^5 rep in the presence of sodium sorbate (0.05 percent) and ascorbic acid was kept at room temperature for 13 days without the development of micro-organisms. Likewise, Cooper (1961) reported that the doses of 2×10^5 rads and 3×10^5 rads were the optimum doses of radiation for preservation of strawberries and cherries, respectively, where Penicillium was completely killed by these doses.

METHODS AND MATERIALS

During the summer and fall months of 1960 and 1961, studies were conducted on apricots, peaches, and pears, which were harvested from orchards at the Howell Field Station, Pleasant View and the Farmington Field Station, Farmington, both of the Utah State University at Logan, Utah.

The harvested produce was immediately sorted in the laboratory for size, maturity, and freedom from injuries. The size, number, and weight of fruits in each treatment were kept nearly constant. The maturities of apricots, peaches, and pears were determined by the Magness-Taylor pressure-tester with a 5/16-inch tip and the average values were recorded as follows:

Crop	Variety	Pressure reading (psi)
Apricot	Moorpark (1960)	6.3; 4.1
	Large Early Montgamet (1960, 1961)	8.8; 6.2
Peach	Gem (1960)	13.9
	Elberta (1960, 1961)	14.3
Pear	Bartlett (1960, 1961)	18.6

Studies conducted are described in the following six experiments.

Chemical Treatments and Effects of Packaging Films on Respiratory Behavior, Fungus Growth, and Marketable Quality of Apricots, Peaches, and Pears

Experiment I: Effects of chemical treatments on respiratory behavior of apricots and peaches

Respiratory studies were made with an apparatus (Figure 3) designed

Figure 3. Claypool and Keefer-type respirometer.

by Claypool and Keefer in 1942. This is a rapid method for determining CO_2 given off by respiring fruits.

Fruits under study, in three replications each, were dipped for two minutes in aqueous solutions of Captan[1] (N-Tri-chloromethylmercapto-4-cyclohexene-1,2-dicarboximide) at 1200 and 2400 ppm, Mycostatin[2] at 100 and 200 ppm, Dowicide-A[3] (sodium-orthophenylphenate) at 1000 and 2000 ppm, and sorbic acid[4] at 5000 and 10,000 ppm. Subsequent to drying, approximately two pounds of the treated fruits along with untreated controls for comparison were placed in a gallon capacity respiratory chamber and then were connected to a Claypool and Keefer respirometer. With this method, the rate of flow of a humidified air stream was controlled by a flowmeter. The air was passed over the known weight of the respiring material and then through a buffered indicator-solution (10 ml. of a 0.001 m $NaHCO_3$ with bromthymol blue as indicator at 0.005 g/l). The light transmission of the solution was measured by means of a Bausch and Lomb colorimeter, using a 620 filter with 595 to 660 millimicrons transmission limits. Respiration readings were recorded on alternate days at 9 a.m. The colorimeter readings were converted to percent CO_2 in the air stream. The results were expressed as mg. of CO_2 per kg. fresh weight per hour, and the average values for the three replicates were plotted against the time in reading. The respirometers

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[1]Tolerance 100 ppm on several fruits and vegetables; California Chemical Company, Ortho Division, Richmond, California.

[2]Experimental material; The Squibb Institute for Medical Research, New Brunswick, New Jersey.

[3]Tolerance 5 to 125 ppm depending upon crop; Dow Chemical Company, Midland, Michigan.

[4]Tolerance 10 to 100 ppm; Chas. Pfizer and Co., Inc., 630 Flushing Avenue, Brooklyn 6, New York.

along with the fruits were kept throughout the experimental period at 40° ± 1° F and 85 ± 2 percent relative humidity. In addition, one more experiment for peaches was conducted at 75° ± 2° F and 35 ± 2 percent relative humidity. The study was terminated as soon as there was indication of a fungus growth.

Experiment II: Effects of chemical treatments on fungus growth

This experiment was conducted in vitro in an attempt to study the direct effects of chemicals on fungus growth. For this, the paper disc-diffusion method was used. Discs of one centimeter in diameter were immersed in the test solutions of Captan at 1200 and 2400 ppm, Mycostatin at 100 and 200 ppm, Dowicide-A at 1000 and 2000 ppm, sorbic acid at 5000 and 10,000 ppm, and in distilled water (as control) until saturated. The discs were allowed to drain for a few seconds before being placed firmly upon agar previously inoculated with the test organisms (Penicillium, Rhizopus, and Alternaria species). The isolation and transfer of organisms was done in the sterilized chamber (Figure 4). For this study, a synthetic media known as Czapek's solution agar was used. Czapek's solution agar is especially suitable for growing Aspergillus, Penicillium, and Norcardia species. Rhizopus and Alternaria species also grow well on it. The experiment was conducted in triplicate and the data were obtained by measuring the area inhibited by the discs immersed in chemicals.

Experiment III: Effects of chemical treatments and packaging films on respiratory behavior, fungus growth, and marketable quality of apricots, peaches, and pears

The study was conducted to determine if chemical treatments and

Figure 4. Isolation and inoculation chamber.

packaging films might be used successfully to extend the freshness and salability of fruits for a longer period of time at refrigeration temperatures.

For this experiment two packaging films--commercial polyethylene and Duratite, a special polyethylene--of thickness 1.5 mil[5] and 2.0 mil, respectively, and of permeability[6] (1270 CO_2, 310 O_2 and 890 CO_2, 268 O_2, respectively) to CO_2 and O_2 were used. The selected fruits were dipped for two minutes in aqueous solutions of Captan at 1200 and 2400 ppm, Mycostatin at 100 and 200 ppm, Dowicide-A at 1000 and 2000 ppm, and sorbic acid at 5000 and 10,000 ppm. Apricots were treated with only the lower concentrations. Control fruits were not dipped in solutions. After drying, the treated and control peaches and apricots were placed in polyethylene and Duratite bags while pears were packaged only in Duratite bags. The bags were stored at 40° ± 1° F and 85 ± 2 percent relative humidity for 35 to 75 days, depending upon the kind of fruit under study.

Evaluations of the effects of packaging films in maintaining CO_2 and O_2 levels within the closed bags were made by an Orsat-type gas analyzer (Figure 5). In gas analysis a measured volume of gas sample is withdrawn from the bag and various components are completely removed by suitable reactions. The percentage decrease in volume is a direct indication of the percent of the component in the original sample. Gas analysis by this apparatus gives the direct percentage of a given gas, provided a sample of 100 ml. is withdrawn. If the sample drawn is less than 100 ml., then the percentage is calculated by the following

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[5] mil = 0.001 inch.

[6] The permeability was assessed at room temperature in cc/100 in.^{2} of films/24 hours/atmosphere of the test gases.

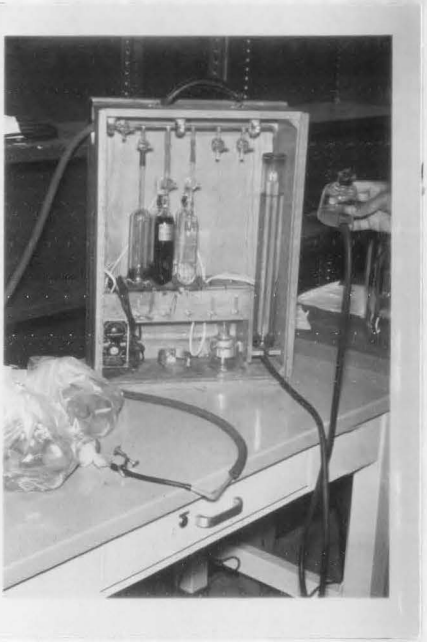

Figure 5. Orsat-type gas analyzer (used to measure CO_2 and O_2 in film bags containing fruits).

equation:

$$\text{Percent component} = \frac{\text{Decrease in volume}}{\text{Volume of sample}} \times 100$$

It is difficult to determine the number of passes required for the absorption of a particular component, because this varies with the design of the pipette, the reagent used, the age of the reagent, and several other factors. Usually, three passes are sufficient for CO_2 and six or more passes may be required for other components such as O_2.

This gas analyzer is used for rapid work of technical accuracy. In our experiments, gas samples were withdrawn through a special device attached to the opening of the bags by the displacement of acidulated water in a 100 ml. burette. The CO_2 in a given sample was absorbed in 40 percent potassium hydroxide solution, while oxygen was absorbed in alkaline pyrogallol. The reactions are shown by the following equations:

$$2\ KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

$$2NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

Potassium hydroxide is commonly used because observation is not hindered by precipitation. When sodium hydroxide is used, precipitation hinders the observation of calibration marks.

The marketable quality of fruits is usually reduced by micro-organisms which grow on them during their storage period. It is well known that Penicillium, Rhizopus, Alternaria, and Monilinia species are the common invaders of the above mentioned fruits after harvest. It was therefore decided not to inoculate apricots and to inoculate peaches and pears with these organisms before the application of the chemicals. The treated fruits were then packaged to determine the effects of chemicals and packaging on pathogens which usually infest these fruits.

Apricots (var. Large Early Montgamet and Moorpark) of canning and shipping maturities were used. The selected fruits were treated with the chemicals--Captan (1200 and 2400 ppm), Mycostatin (100 and 200 ppm), Dowicide-A (1000 and 2000 ppm), and sorbic acid (5000 and 10,000 ppm)--and then packaged in polyethylene and Duratite bags. For another phase of the experiment, peaches (var. Elberta) and pears (var. Bartlett) of shipping maturity were inoculated artificially by dipping them in a mixture of Penicillium, Rhizopus, Alternaria, and Monilinia spores suspended in water. This spore suspension was made in the following manner. Fruits were needle-inoculated with pure cultures of Penicillium, Rhizopus, Alternaria, and Monilinia species. When these inoculated fruits were completely decayed, the comminution of the invaded flesh was attained by diluting this flesh with an equal volume of distilled water. The desired consistency of this inoculum was obtained by further dilutions until an average of about 25 spores could be counted in a given microscopic field at X430.

After a 48-hour period of incubation at 75° F, inoculated fruits were treated with above-mentioned chemicals at the concentrations specified before placing inside the plastic bags. The bags containing the experimental fruits were then placed in storage at 40° ± 1° F and 85 ± 2 percent relative humidity. Representative replications of each treatment were opened periodically to count and to calculate the marketable fruits and to identify the organisms developing on the fruits.

Effects of Ionizing Radiations and Packaging Films on Respiratory Behavior, Fungus Growth, and Subsequent Marketable Quality of Peaches

Experiment IV: Effects of ionizing radiations on respiratory behavior of peaches

The peaches (vars. Elberta and Gem) were irradiated with both beta and gamma rays at 0 x 10^5 (control), 1 x 10^5, 3 x 10^5, and 5 x 10^5 rads.

Beta radiation. Peaches (var. Elberta) were irradiated with beta rays. The radiation process was performed with a Van de Graff accelerator at California Research Corporation, Richmond, California. This accelerator consisted of power supplies, a belt-drive motor and pulleys, a charging belt, a voltage generating column, and a high voltage terminal. The major component of the accelerator was the voltage generator assembly. This was a 2.0 million volt electron accelerator. The accelerator operation is illustrated in Figure 6.

Twenty-four hours after harvest, peaches were weighed and put into Duratite bags. The number and weight of fruit in each bag was the same for each radiation dose. The fruits were irradiated in three replications for each dose. These peaches were not inoculated before being irradiated with beta rays. They were irradiated after they were packaged in the film bags, and the air inside the bags was exhausted before irradiation to facilitate spreading of peaches in a layer on the radiation belt.

Gamma radiation. The radiation facility is situated at the Dugway Proving Grounds, Dugway, Utah. The radiation source is spent-fuel elements from the Materials Testing Reactor located at Scoville, Idaho.

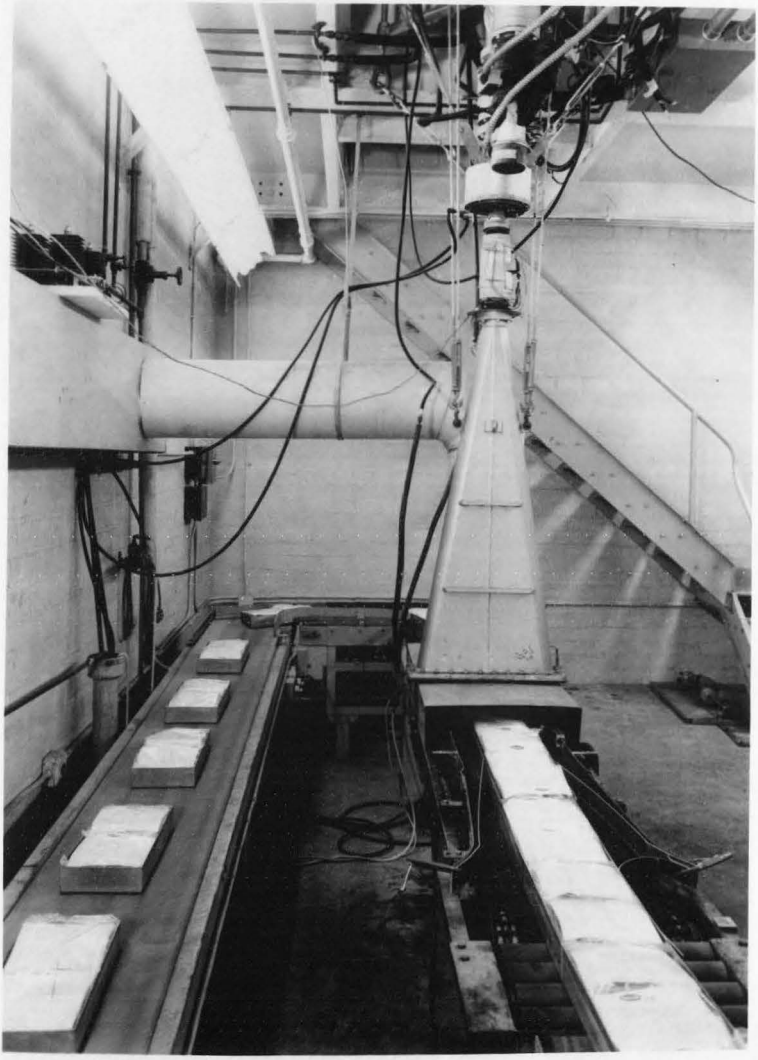

Figure 6. Van de Graff electron accelerator in operation.

The material is irradiated under thick walls of lead and concrete. When the facility is in operation, a tube near its center revolves while carying cans of experimental materials. This revolving tube, shown in Figure 7, is driven at about 2 revolutions per minute. This is adequate to insure uniform radiation dosage on all sides of the material being irradiated, even though the fuel elements are not uniform in the emission of radiation.

Peaches (var. Gem) were placed in No. 10 cans before irradiation. Three perforations were made at the bottom of each can to facilitate air circulation and to prevent excessive temperature rises during the irradiation process.

Peaches of both varieties (Elberta and Gem) were brought to the laboratories after irradiation. There they were taken out (of the bags in case of beta radiation and of the cans in case of gamma radiation) and placed in gallon capacity respiring chambers in three replications each, to assess the respiratory behavior using the method described in Experiment I.

Experiment V: Effects of ionizing radiation on fungus growth

For this experiment Penicillium, Rhizopus, and Alternaria species were established on Czapek's media in petri dishes. Three days after their establishment on the media the organisms were irradiated with beta rays 0 x 10^5 (control), 1 x 10^5, 3 x 10^5, and 5 x 10^5 rads in three replications to study the effects of beta rays on the survival of the fungi.

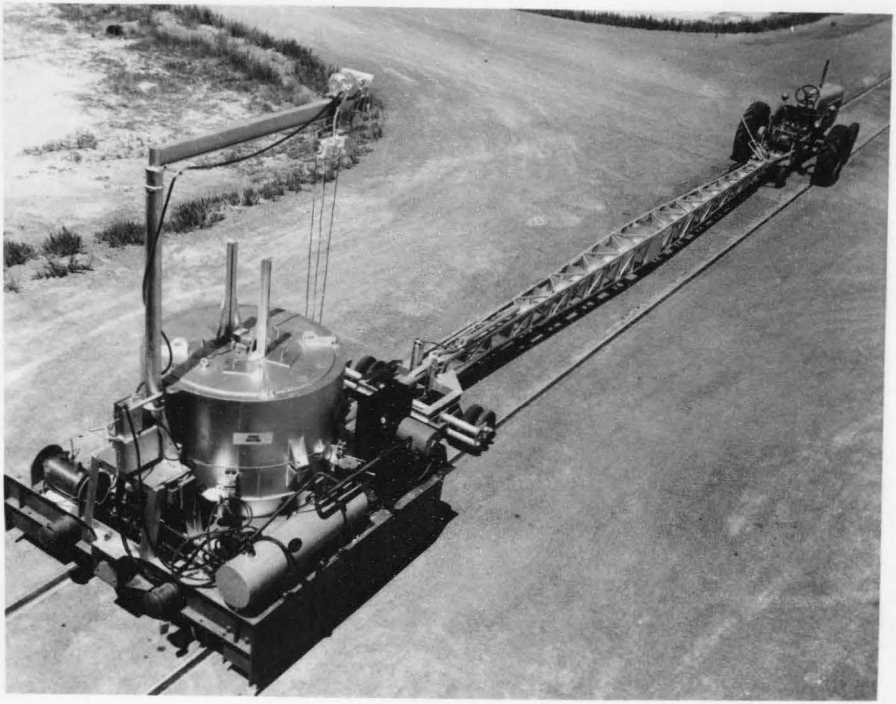

Figure 7. Cobalt-60 gamma radiation facility at the Dugway Proving Grounds, Dugway, Utah (note that the assembly is movable).

Experiment VI. Effects of packaging films and ionizing radiations on respiratory behavior, fungus growth, and marketable quality of peaches

The peaches (var. Elberta and Gem) were irradiated with beta and gamma radiations as described in Experiments 4 and 5.

Since the beta radiation process was performed after packaging the peaches in Duratite film bags, they were stored as such at 40° F and 85 percent relative humidity for respiration and fungus control studies. On the other hand, peaches which were irradiated with gamma rays after putting them in No. 10 cans were taken out of the cans and placed in Duratite and polyethylene film bags for both the studies mentioned above.

The atmospheric (CO_2 and O_2) analysis and marketable quality of peaches, for both beta and gamma radiation treatments, were made by the similar process mentioned in Experiment III.

Wherever possible, the data obtained were anlyzed for statistical significance.

RESULTS AND DISCUSSION

The investigations which are discussed in the following six experiments are concerned with the prevention of post-harvest losses induced by respiration and fungal growth on apricots, peaches, and pears.

Experiment I: Effects of Chemical Treatments on Respiratory Behavior of Apricots and Peaches

This study was conducted to see if the climacteric can be extended by various chemical treatments under given conditions of temperature and relative humidity in order to increase the shelf-life of certain fruits.

Apricots (var. Large Early Montgamet)

The respiratory behavior of the chemically treated fruit was studied by Claypool and Keefer (1942) apparatus. The rate of air flow over fruit was controlled by flowmeters at 13 to 18 liters per hour.

The results obtained, with original dye solution reading 55, in mg. CO_2 per Kg. fruit per hour, were plotted in Figure 8 for each chemical including non-treated control. The irregular behavior of the respiratory curves with the advancement of time is natural among fruits (Biale, 1950; Smock, 1944; Claypool and Allen, 1951). As it was said by Biale in 1950, any treatment which delays the onset of the climacteric also delays senescence. Therefore, the climacteric rise is by far the most important factor to be considered in determining the

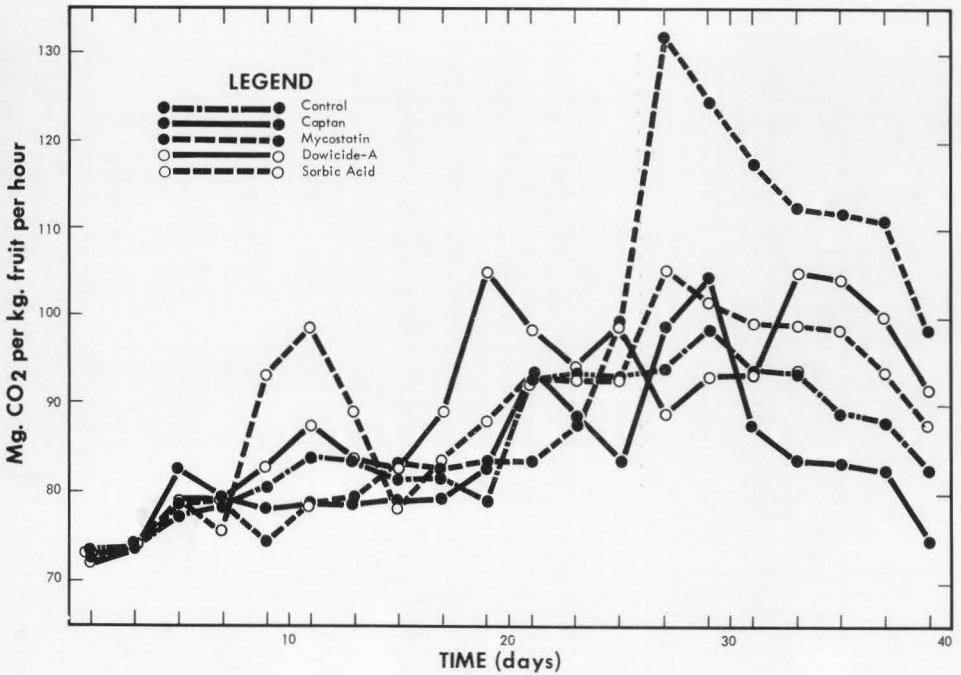

Figure 8. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (1200 ppm, 100 ppm, 1000 ppm, and 5000 ppm, respectively) on the respiratory behavior of apricots (var. Large Early Montgamet) stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

biological spectrum of the fruits. In Figure 8, the climacteric rise in control, Captan, Dowicide-A, sorbic acid, and Mycostatin is on 30, 30, 34, 28, and 28 days, respectively. It seems that Dowicide-A has delayed the climacteric rise by 4 days whereas sorbic acid and Mycostatin have accelerated the rise by 2 days. These variations might be explained on the basis of induced disturbances in the normal functioning of the respiratory enzyme systems (Desrosier, 1959). Among the four treatments, Mycostatin seems to be stimulating the respiratory process to a larger extent than the others; the respiratory results obtained in 1961 were more or less similar to those obtained in 1960 (Figure 9).

Apricots (var. Moorpark)

The general pattern of the curves for all the treatments was similar to those of Large Early Montgamet. The climacteric rise in the cases of control, Captan, Dowicide-A, sorbic acid, and Mycostatin was observed on 29, 21, 33, 31, and 27 days, respectively (Figure 10). This means that Dowicide-A and sorbic acid delayed the climacteric by 4 and by 2 days, respectively, whereas Captan and Mycostatin induced the climacteric 8 and 2 days earlier, respectively. It can be noticed from these results that varieties behave differently in their respiratory behavior under given conditions. Also, chemicals have different effects on different varieties (Eaks, 1952; Denny, 1924; and Allen, 1953). In general, the climacteric height induced by the chemicals was in the following descending order: Mycostatin, Dowicide-A, Captan, control, and sorbic acid.

The life of the fruit depends upon the height of the climacteric peak and the slope of the pre-climacteric and post-climacteric curves.

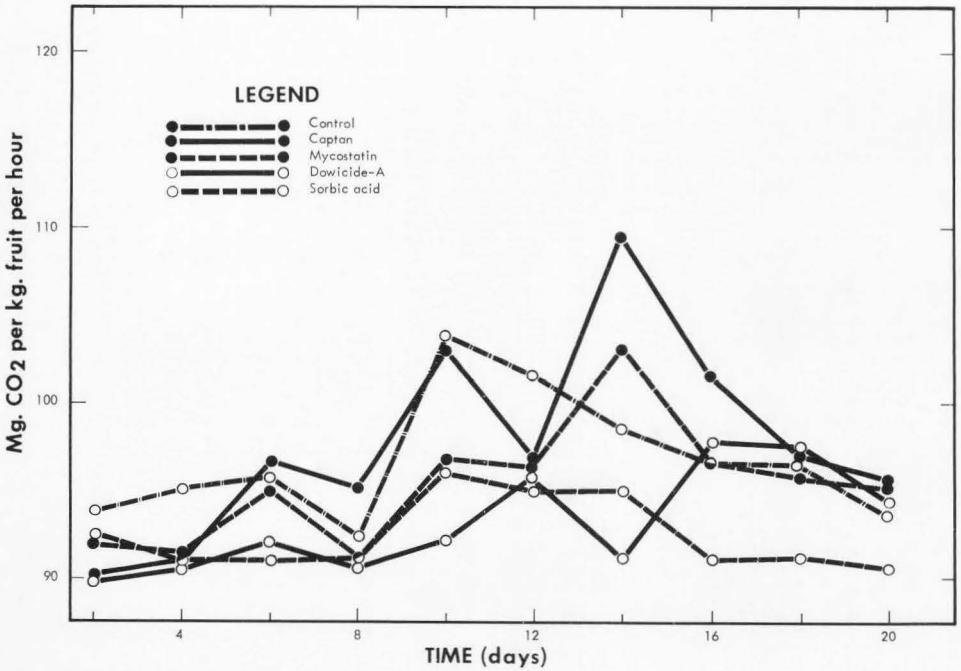

Figure 9. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (2400 ppm, 200 ppm, 2000 ppm, and 10,000 ppm, respectively) on the respiratory behavior of apricots (var. Large Early Montgamet) stored at 40° F and 85 percent relative humidity for 20 days. Observations started 1 day after storage (1961).

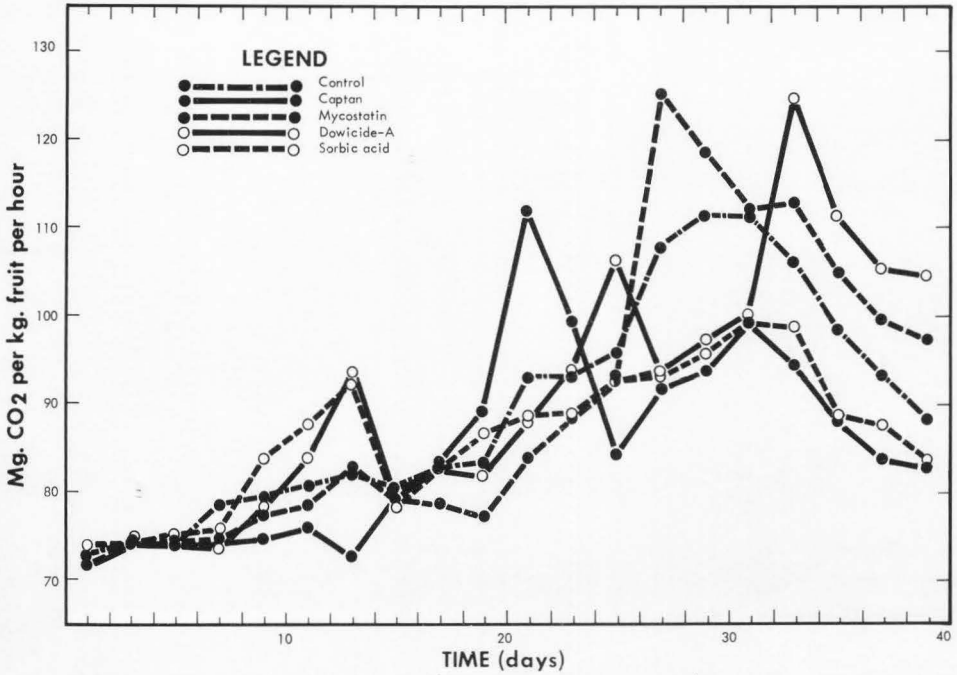

Figure 10. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (1200 ppm, 100 ppm, 1000 ppm, and 5000 ppm, respectively) on respiratory behavior of apricots (var. Moorpark) stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

The slower the rise and fall of the curve, the longer the storage life of the fruit becomes. In general, the curves induced by all of the treatments rise slowly and just after the climacteric peak they fall quickly and then more slowly.

Analysis of variance for both of the above-mentioned varieties considering the effects of elapsed storage time and chemical treatments on the evolution of CO_2 is presented in appendix table 11. This analysis shows that the amount of CO_2 given off by the fruits measured at alternate days does not significantly differ until after 7 days of storage. During the seventh to thirty-ninth day of storage, the difference in CO_2 evolution became significant. As far as chemical treatments are concerned, Captan is better in inhibiting the respiratory rate significantly as compared to other chemicals which seem to stimulate it in the following order: sorbic acid, Dowicide-A, and Mycostatin. Similar statistical results can be seen in appendix table 12 for 1961 data on apricots (var. Large Early Montgamet).

Peaches (var. Elberta)

The study was conducted at 40° F and 85 percent relative humidity, and at 75° F and 35 percent relative humidity. The data for CO_2 in mg./kg./hr. given off by the fruits are graphically presented in Figure 11 for 40° F and in Figure 12 for 75° F and 35 percent relative humidity. The climacteric rise of peaches was much faster than that of apricots already discussed. The climacteric point occurred after 22 days in the control and Captan treatments. Dowicide-A, sorbic acid, and Mycostatin induced the climacteric on 24, 26, and 16 days, respectively. It can be said that the climacteric was delayed 2 days by the Dowicide-A

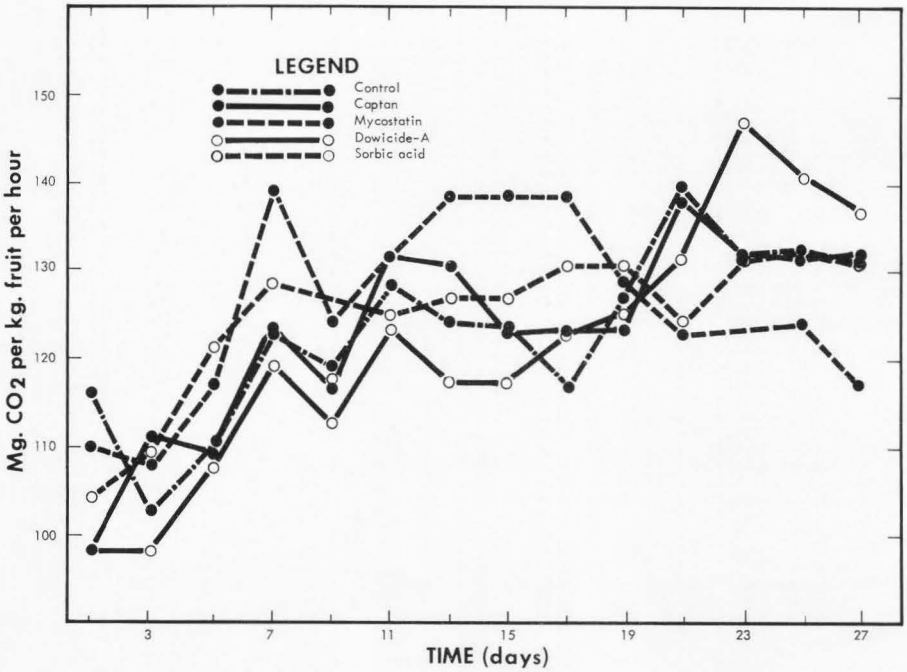

Figure 11. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (1200 ppm, 100 ppm, 1000 ppm, and 5000 ppm, respectively) on respiratory behavior of peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 28 days. Observations started 1 day after the storage (1960).

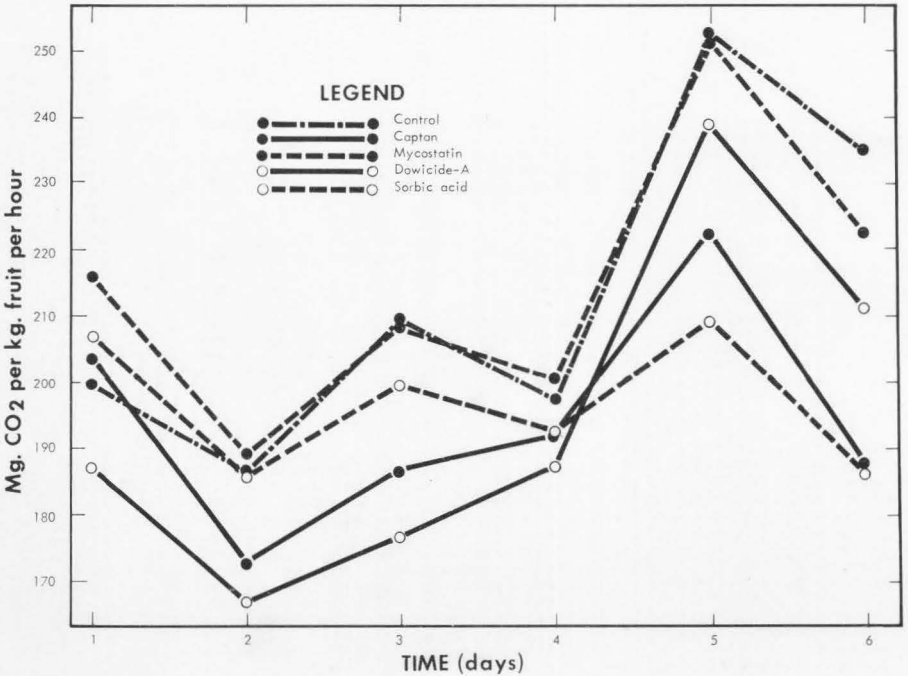

Figure 12. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (1200 ppm, 100 ppm, 1000 ppm, and 5000 ppm, respectively) on respiratory behavior of peaches (var. Elberta) stored at 75° F and 35 percent relative humidity for 6 days. Observations started 1 day after the storage (1960).

treatment and 4 days by the sorbic acid treatment, whereas Mycostatin induced the climacteric point 6 days earlier than that of the controls. The highest and most delayed respiratory peak was attained by Dowicide-A, followed by controls, Captan, Mycostatin, and sorbic acid in descending order, respectively. These data show that the respiratory systems are being upset by the chemical treatments. Some chemicals increase the respiratory rate; other chemicals decrease it (Woodruff and Crandall, 1958). This effect of the chemical treatments may be explained by assuming that these chemicals influence the respiratory enzyme systems which degrade the complex compounds into more simple forms that are more readily used directly in the process of respiration.

When peaches were held at room temperature (75° F), the food reserves were exhausted within the fruits during the first 6 days because respiration proceeded much faster than in similar fruits held at 40° F (Claypool and Allen, 1951; Tewfik and Scott, 1954; and Lyons and Rappaport, 1959). The climacteric in all of the treatments including nontreated controls was reached on the fifth day of storage.

The height of the climacteric peaks induced by the treatments in their descending order were as follows: controls (nontreated), Mycostatin, Dowicide-A, Captan, and sorbic acid. This shows that total CO_2 given off by the fruits was inhibited by the chemical treatments. However, sorbic acid was by far the most effective at 75° F. It is well-known that temperature plays a great role in stimulating or inhibiting the respiratory systems of all living fruits (Smock, 1944). Results obtained in 1961 were similar to those obtained in 1960 (Figure 13 and appendix table 12).

The statistical analysis for peaches stored at both the temperatures

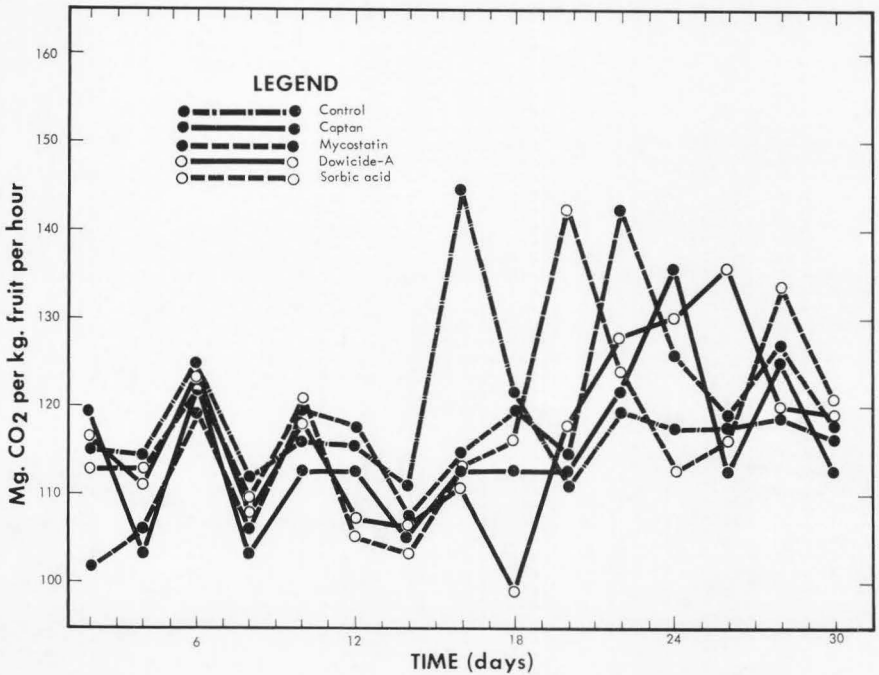

Figure 13. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (2400 ppm, 200 ppm, 2000 ppm, and 10,000 ppm, respectively) on respiratory behavior of peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 30 days. Observations started 1 day after storage (1961).

mentioned above for the effects of elapsed storage time and chemical treatments on the evolution of CO_2 is presented in appendix table 11. This table shows that the amounts of CO_2 given off by the fruits measured at alternate days significantly differ throughout the storage period. For the chemical treatments, at 75° F Captan and Dowicide-A reduce the respiratory rate significantly while sorbic acid and Mycostatin seem to stimulate this rate. Similar statistical results can be seen in appendix table 12 for 1961 data. In contrast to this the chemical treatments at 40° F show no significant differences in their effect on the evolution of CO_2.

Experiment II: Effects of Chemical Treatments on Fungus Growth

This study in vitro was conducted at 40° F and 85 percent relative humidity and 75° F and 35 percent relative humidity. The results obtained for the fungus-growth-inhibiting effects of Captan, Mycostatin, Dowicide-A, and sorbic acid (1200 and 2400 ppm, 100 and 200 ppm, 1000 and 2000 ppm, and 5000 and 10,000 ppm, respectively) on Penicillium, Rhizopus, and Alternaria species are presented in table 1. It is clear from this table that at both temperatures (40° and 75° F) the chemicals are more or less similar in their effects in inhibiting the growth of the organisms mentioned above. Captan at both concentrations is by far the most effective chemical in inhibiting growth of the fungi, whereas other chemicals in their descending order of effectiveness are Mycostatin, Dowicide-A, and sorbic acid (Almandil, 1960; and DiMarco, 1959). The same sequence of the effectiveness of the chemicals on fungus growth was observed in vivo (Experiment III). These results can also be

Table 1. Effects of chemical treatments on fungus growth in vitro at 75° F and 35 percent relative humidity and at 40° F and 85 percent relative humidity. (Data collected 7 days after treatment at 75° F and 18 days after treatment at 40° F, 1961).

Fungus	Chemical	Concentration ppm	Effectiveness[a] of the treatment at 75° F	Effectiveness[a] of the treatment at 40° F
Alternaria	Control	—	+ + + + +	+ + + + +
	Sorbic acid	5000	+ + + +	+ + + +
		10000	+ + +	+ + + +
	Dowicide-A	1000	+ + +	+ + +
		2000	+ + +	+ +
	Mycostatin	100	+ + +	+ +
		200	+ +	+ +
	Captan	1200	+ +	+ +
		2400	+	+
Penicillium	Control	—	+ + + + +	+ + + + +
	Sorbic acid	5000	+ + + +	+ + + +
		10000	+ + + +	+ + +
	Dowicide-A	1000	+ + +	+ + +
		2000	+ + +	+ +
	Mycostatin	100	+ + +	+ +
		200	+ +	+ +
	Captan	1200	+	+ +
		2400	+	+
Rhizopus	Control	—	+ + + + +	+ + + + +
	Sorbic acid	5000	+ + + +	+ + + +
		10000	+ + + +	+ + +
	Dowicide-A	1000	+ + +	+ + +
		2000	+ + +	+ +
	Mycostatin	100	+ + +	+ +
		200	+ +	+ +
	Captan	1200	+ +	+
		2400	+	+

[a] + = no growth. ++ = slight growth. +++ = moderate growth. ++++ = normal growth. +++++ = profuse growth.

substantiated from Figures 14 and 15. It was also noticed that lower and higher concentrations of the chemicals mentioned above had more or less similar growth-inhibiting effects on fungi.

Experiment III: Effects of Chemical Treatments and Packaging Films on the Respiratory Behavior and Marketable Quality of Apricots, Peaches, and Pears

This experiment was conducted on apricots, peaches, and pears to study the effects of chemical dips followed by packaging in polyethylene and Duratite bags on respiration, storage, and quality of the fruit. In experiments with apricots (var. Large Early Montgamet) the packaging material appeared to be more important than the chemical treatment. Polyethylene bags maintained high O_2 and low CO_2 contents for a longer period of time than the Duratite bags. This difference probably reflects a difference in permeability of the plastic materials to CO_2 and O_2 gases.

It was noticed that the level of CO_2 in Duratite bags rose as high as 4.8 percent at 6 days whereas in polyethylene bags it rose to only 3.5 percent at 15 days (Figure 16). With continued respiration O_2 soon became the limiting factor and therefore the CO_2 level in both types of bags remained fairly constant during the 37 days of storage. This situation might have occurred because the accumulation of CO_2 and reduction of O_2 inhibited the respiratory rate of apricots (Kidd and West, 1936, working on pears; and Van Doren, 1939, working on apples). Polyethylene bags, which maintained lower levels of CO_2 around apricots, were better in keeping the fruit for longer periods of time than the Duratite bags, which maintained higher levels of CO_2. This suggests

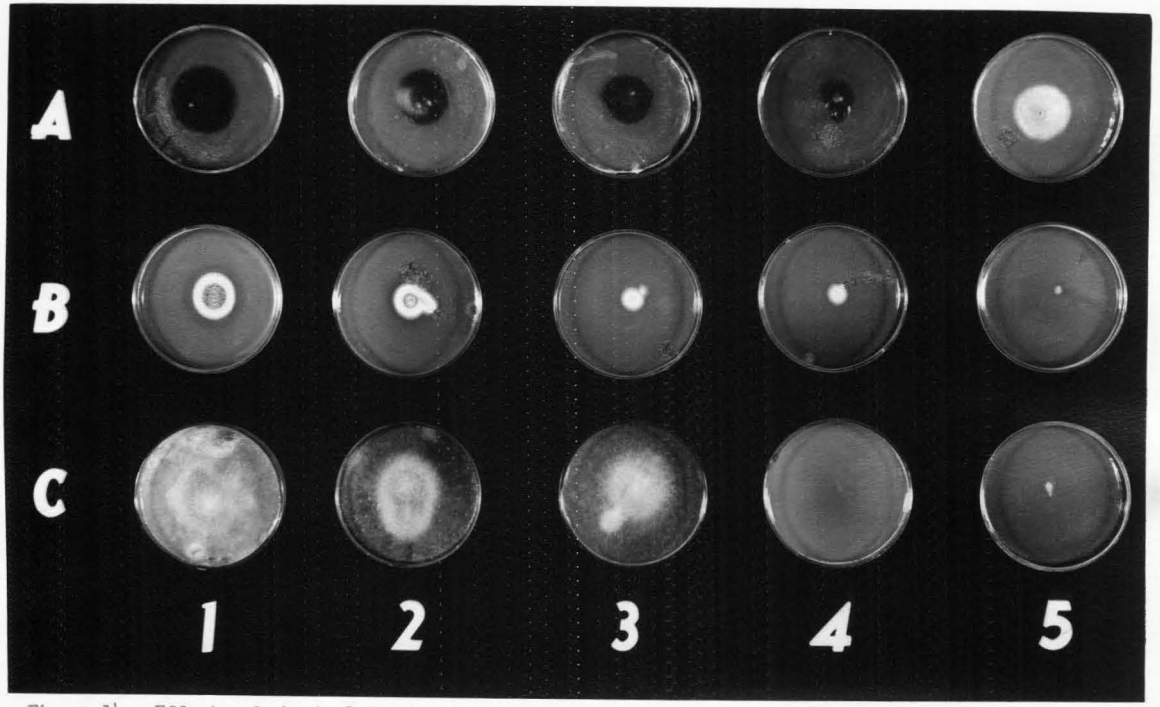

Figure 14. Effects of chemical treatments on fungus growth in vitro at 40° F and 85 percent relative humidity (photographed 18 days after chemical treatments). Top to bottom: A = Alternaria, B = penicillium, C = Rhizopus. Left to right: 1 = control; 2 = sorbic acid, 5000 ppm; 3 = Dowicide-A, 1000 ppm; 4 = Mycostatin, 100 ppm; 5 = Captan, 1200 ppm (1960).

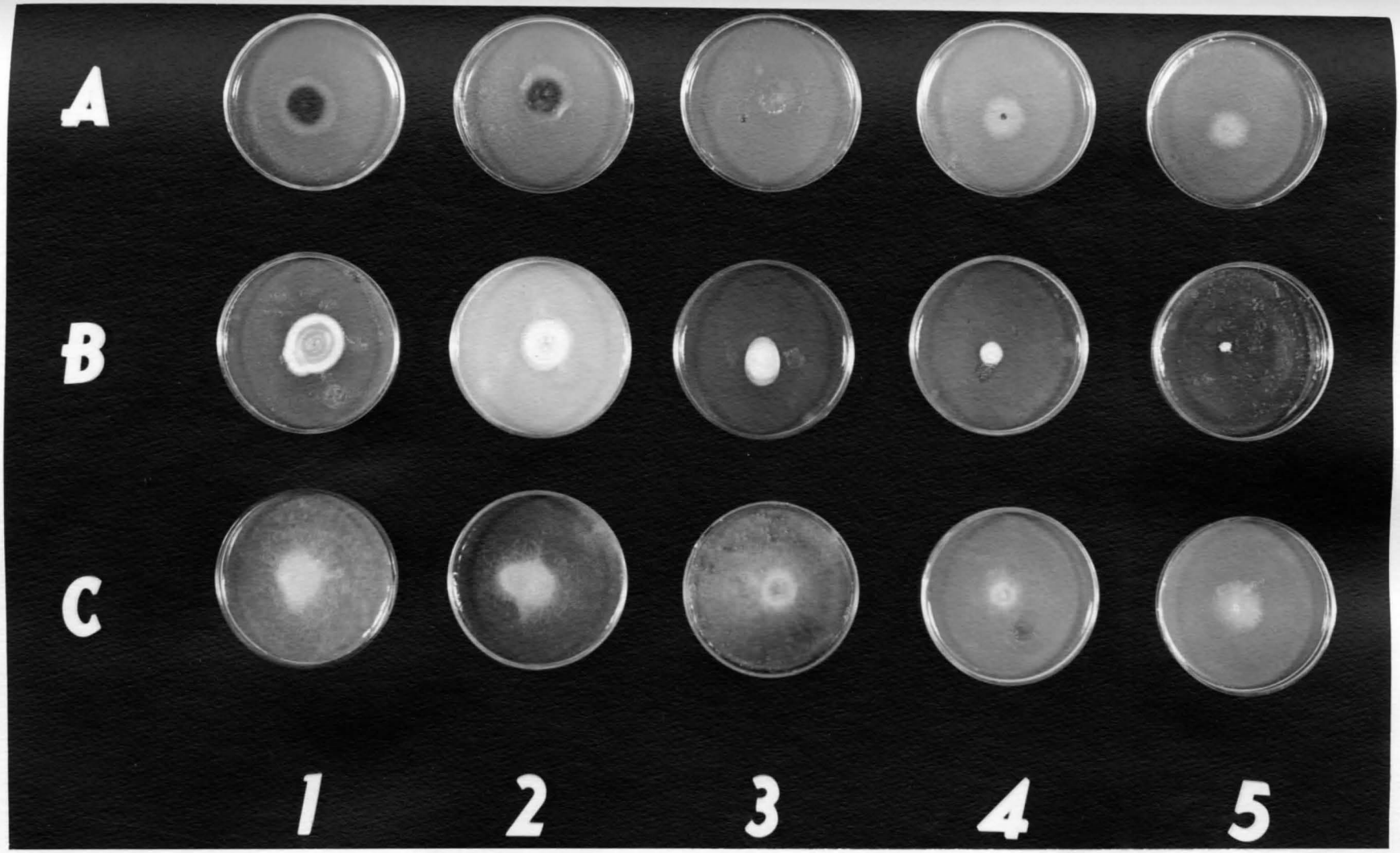

Figure 15. Effects of chemical treatments on fungus growth *in vitro* at 40° F and 85 percent relative humidity (photographed 18 days after the chemical treatments). Top to bottom: A = *Alternaria*, B = *penicillium*, C = *Rhizopus*. Left to right: 1 = control; 2 = sorbic acid, 10,000 ppm; 3 = Dowicide-A, 2000 ppm; 4 = Mycostatin, 200 ppm; 5 = Captan, 2400 ppm (1961).

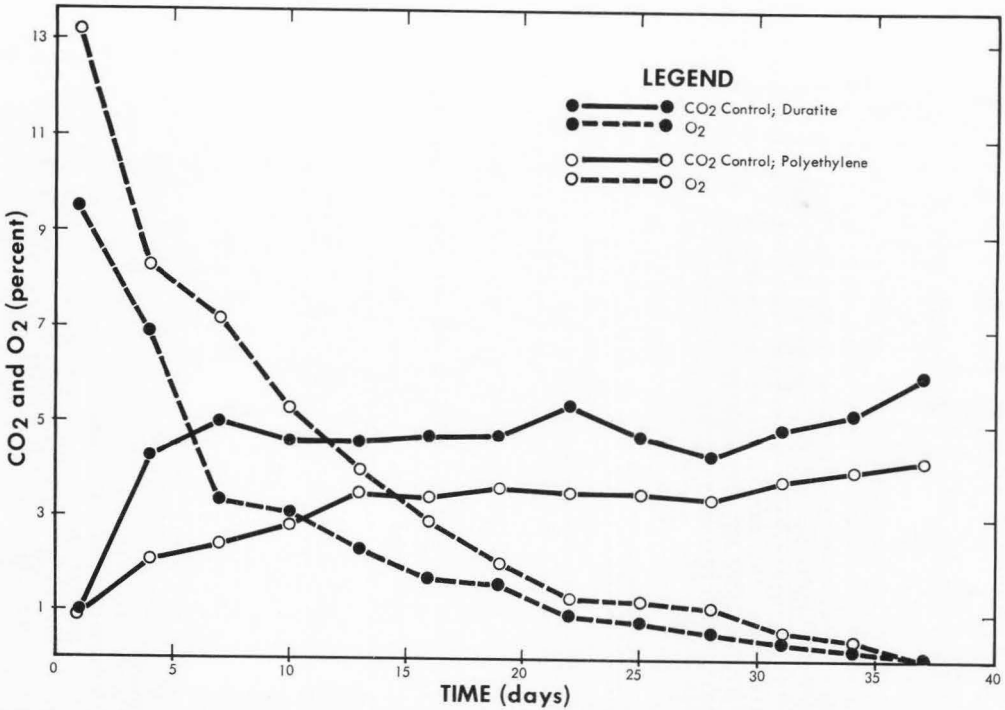

Figure 16. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid on the respiratory behavior of apricots (var. Large Early Montgamet) packaged in Duratite and polyethylene films and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage. (The curves presented in this figure serve as nontreated controls to be used for the comparison with curves presented in Figures 17 to 20, inclusive, 1960).

that apricots cannot tolerate 5 percent or higher levels of CO_2 at 40° F and probably will store better at 3.5 percent or lower levels of CO_2 concentration around them.

It can be noticed from Figures 17 and 18 that Captan and Mycostatin maintain lower levels of CO_2 than Dowicide-A and sorbic acid. It seemed that sorbic acid stimulated the respiratory rate and maintained higher levels of CO_2 inside the Duratite bags, and hence it was a poor treatment in increasing the shelf life[1] of the fruit (tables 2 and 3 and Figure 19). Therefore, there was a high correlation between respiratory rate and length of keeping quality of this fruit. High respiration rates deplete carbohydrate stores rapidly to cause rapid deterioration of the fruits (Gourley and Hopkins, 1931, working on apples). If we note Figures 20 and 21 and tables 2 and 3, it seems that polyethylene bags and prepackaging treatments with Captan and Mycostatin applied to apricots maintain lower levels of CO_2 and hence are best in increasing shelf life of the fruit. Captan is a better treatment than Mycostatin. Dowicide-A and sorbic acid with the polyethylene bag combination do not differ from each other in maintaining CO_2 and O_2 concentrations.

Regardless of the chemical treatments, the comparison between bag materials (polyethylene and Duratite) in maintaining CO_2 and O_2 levels can be made in Figures 22 and 23. These figures show a significant difference between the two kinds of films for holding CO_2 as well as O_2. In studies with apricots (var. Moorpark), the results were similar to those obtained with Large Early Montgamet; both varieties of apricots

[1]The term "shelf life" as used in this dissertation refers to the period during which the fruit may be held and subsequently ripened in a normal manner without showing scald, or flesh disorder, and still remain marketable for several days after becoming ripe. It refers to the period of marketability rather than to a period in which a cessation of metabolic activity occurs.

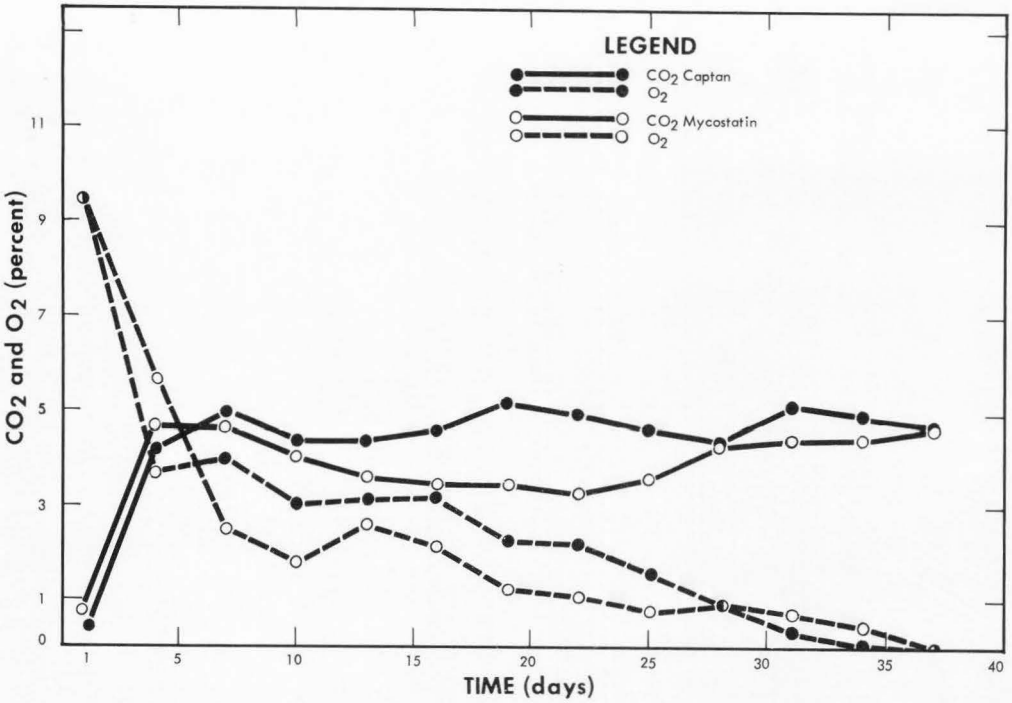

Figure 17. Effects of Captan and Mycostatin (1200 ppm and 100 ppm) on respiratory behavior of apricots (var. Large Early Montgamet) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

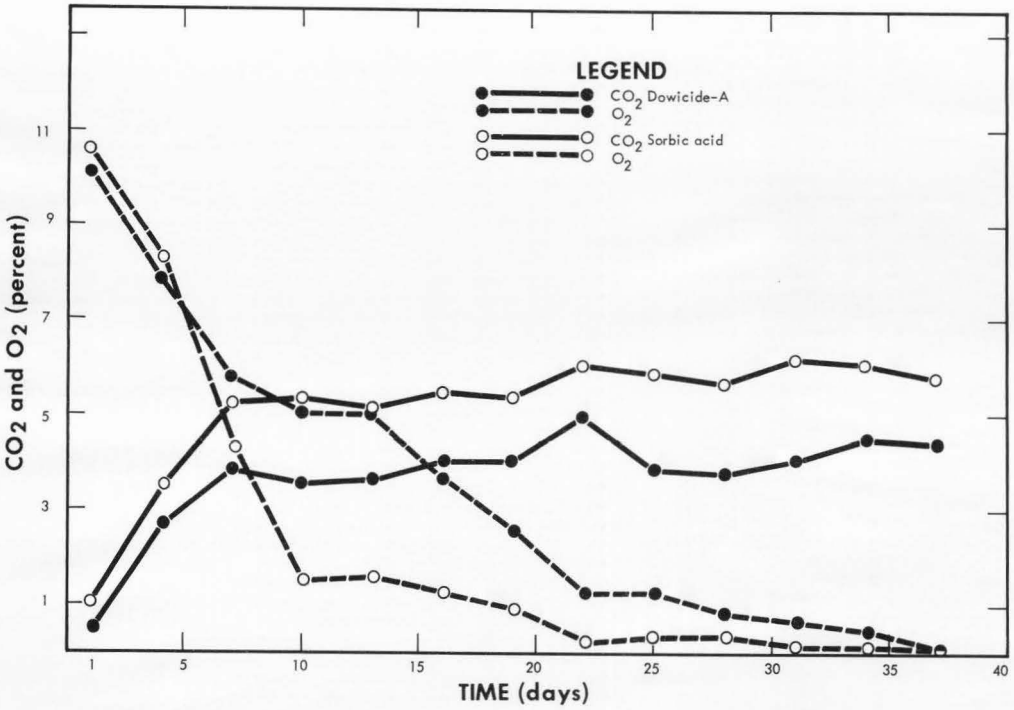

Figure 18. Effects of Dowicide-A and sorbic acid (1000 ppm and 5000 ppm) on respiratory behavior of apricots (var. Large Early Montgamet) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

Table 2. Effects of chemical treatments and packaging films on percentage of marketable fruits and fungus growth on apricots (var. Large Early Montgamet) of canning maturity[a] stored at 40° F and 85 percent relative himidity for 60 days (observations taken at 40, 50, and 60 days intervals, 1960)

Days in storage	Chemical	Concentration ppm	Packaging film: Duratite — No. of fruits	Duratite — Percent marketable fruits	Duratite — Fungi observed	Polyethylene — No. of fruits	Polyethylene — Percent marketable fruits	Polyethylene — Fungi observed
40	Control		59	37.29	Penicillium Rhizopus	60	30.00	Penicillium Rhizopus
	Captan	1200	58	87.93	Penicillium	55	90.90	Penicillium
	Mycostatin	100	59	74.57	Penicillium	63	79.36	Penicillium
	Dowicide-A	1000	55	83.64	Penicillium	61	59.02	Penicillium
	Sorbic acid	5000	47	40.42	Penicillium Rhizopus	53	54.71	Penicillium
50	Control		57	0.00	Penicillium Rhizopus Alternaria	50	4.00	Penicillium Rhizopus Alternaria
	Captan	1200	60	26.00	Penicillium	52	65.38	Penicillium
	Mycostatin	100	51	31.37	Penicillium	64	30.15	Penicillium
	Dowicide-A	1000	48	4.16	Penicillium	57	1.75	Penicillium
	Sorbic acid	5000	51	3.92	Penicillium	63	0.00	Penicillium Rhizopus
60	Control		55	0.00	Penicillium Rhizopus Alternaria	57	0.00	Penicillium
	Captan	1200	57	15.79	Penicillium	57	24.56	Penicillium
	Mycostatin	100	60	5.00	Penicillium	60	6.66	Penicillium
	Dowicide-A	1000	51	0.00	Penicillium	54	0.00	Penicillium
	Sorbic acid	5000	57	0.00	Penicillium Rhizopus Alternaria	60	0.00	Penicillium Rhizopus Alternaria

[a] Canning maturity refers to the stage of firm ripe apricots at which they are usually processed by canning.

Table 3. Effects of chemical treatments and packaging films on percentage of marketable fruits and fungus growth on apricots (var. Large Early Montgamet) of shipping maturity[a] stored at 40° F and 85 percent relative humidity for 60 days (observations taken at 40, 50, and 60 days intervals, 1960)

Days in storage	Chemical	Concentration ppm	Packaging film: Duratite — No. of fruits	Duratite — Percent marketable fruits	Duratite — Fungi observed	Polyethylene — No. of fruits	Polyethylene — Percent marketable fruits	Polyethylene — Fungi observed
40	Control		62	50.00	Penicillium Rhizopus	58	53.45	Penicillium Rhizopus
	Captan	1200	59	94.91	Penicillium	55	96.36	Penicillium
	Mycostatin	100	59	83.05	Penicillium	63	90.47	Penicillium
	Dowicide-A	1000	55	89.09	Penicillium	61	62.29	Penicillium
	Sorbic acid	5000	44	59.09	Penicillium Rhizopus	53	66.04	Penicillium
50	Control		57	1.75	Penicillium Rhizopus Alternaria	51	13.72	Penicillium Rhizopus Alternaria
	Captan	1200	60	33.33	Penicillium	53	73.58	Penicillium
	Mycostatin	100	51	50.88	Penicillium	63	46.03	Penicillium
	Dowicide-A	1000	48	12.50	Penicillium	64	28.12	Penicillium
	Sorbic acid	5000	51	5.88	Penicillium	57	7.02	Penicillium Rhizopus
60	Control		55	0.00	Penicillium Rhizopus Alternaria	57	0.00	Penicillium
	Captan	1200	57	24.56	Penicillium	57	35.09	Penicillium
	Mycostatin	100	60	13.33	Penicillium	60	10.00	Penicillium
	Dowicide-A	1000	54	1.85	Penicillium Rhizopus	54	0.00	Penicillium
	Sorbic acid	5000	51	0.00	Penicillium Rhizopus Alternaria	60	0.00	Penicillium Rhizopus Alternaria

[a]Shipping maturity refers to the stage of mature green apricots at which they are usually shipped to distant markets.

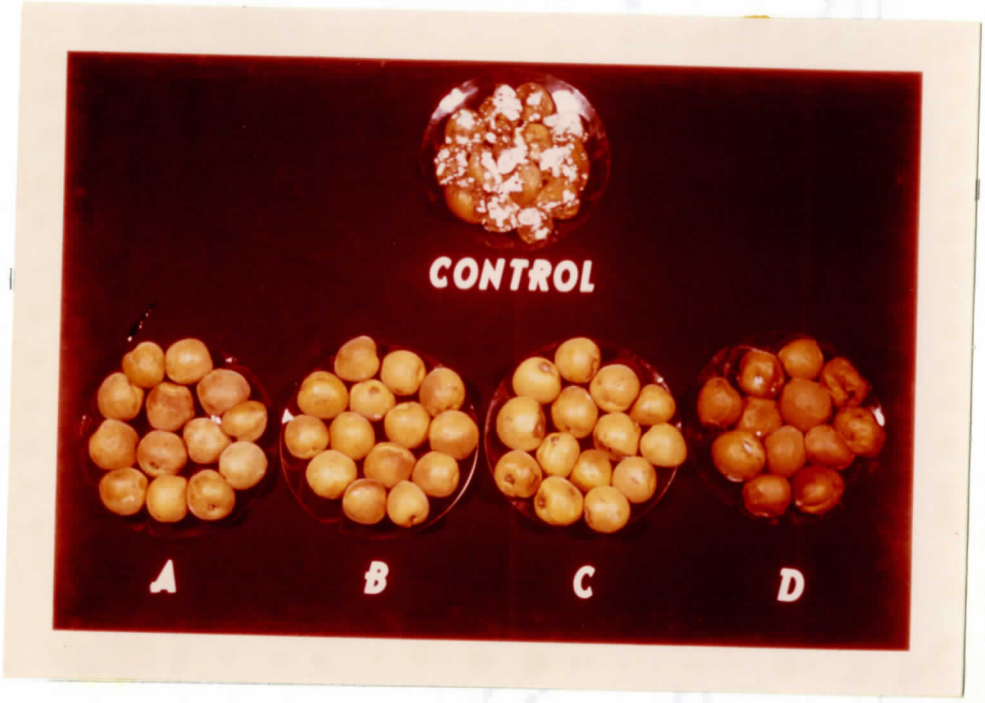

Figure 19. Effects of chemical treatments and Duratite film on the physical quality and fungus growth on apricots (var. Large Early Montgamet). Photographed 60 days after the chemical treatments. Left to right: A = Captan, 1200 ppm; B = Dowicide-A, 1000 ppm; C = Mycostatin, 100 ppm; D = sorbic acid, 5000 ppm.

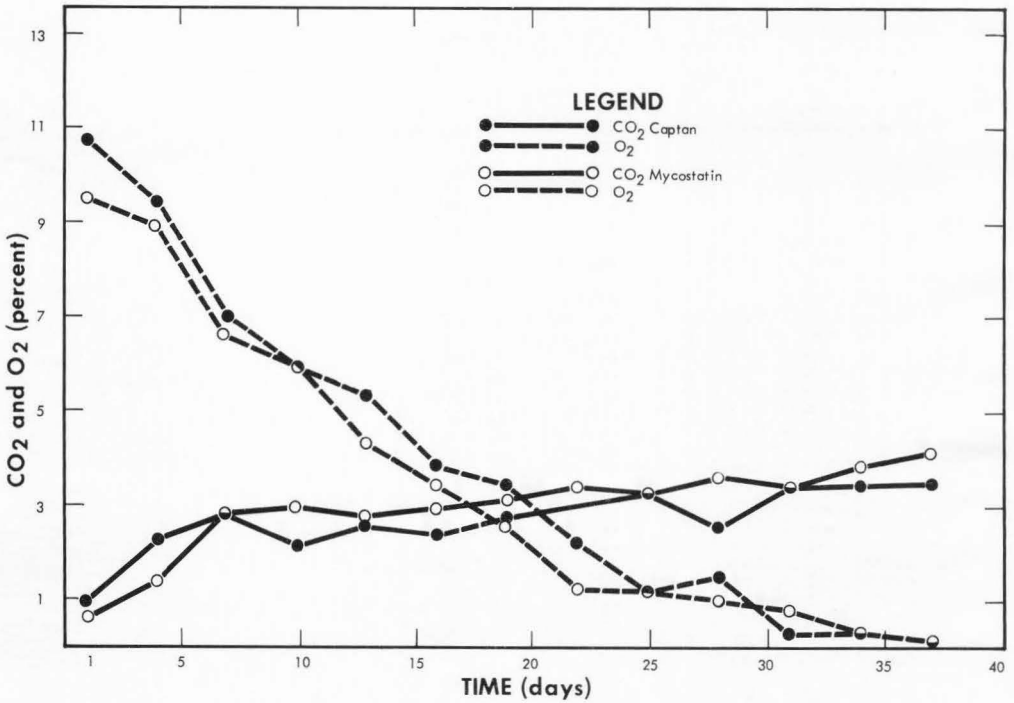

Figure 20. Effects of Captan and Mycostatin (1200 ppm and 100 ppm) on respiratory behavior of apricots (var. Large Early Montgamet) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

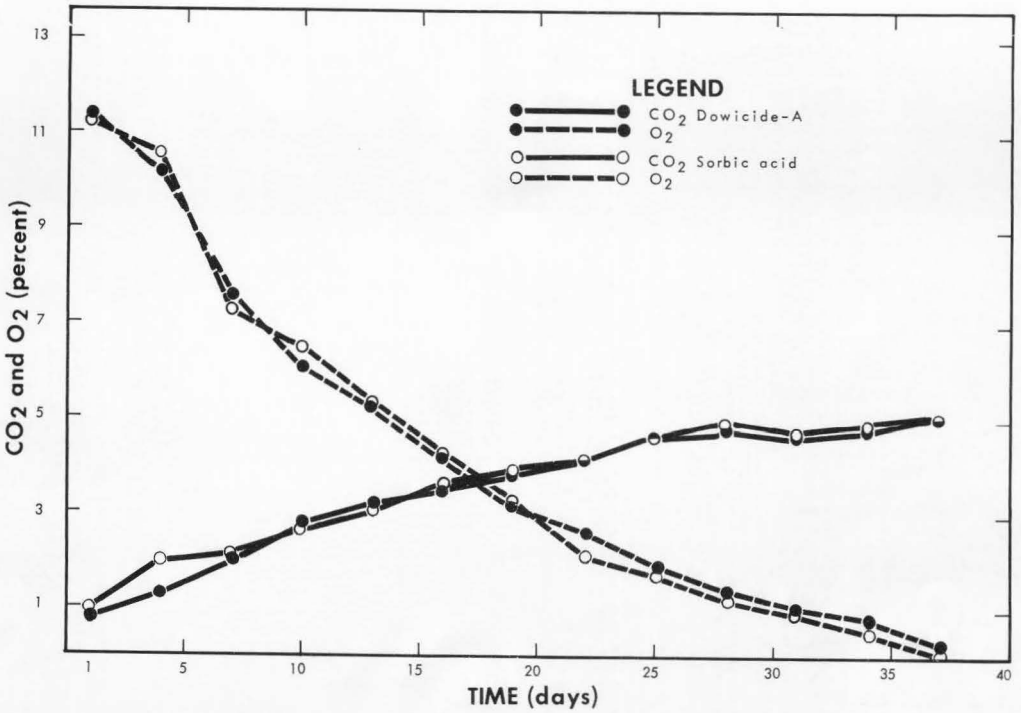

Figure 21. Effects of Dowicide-A and sorbic acid (1000 ppm and 5000 ppm) on respiratory behavior of apricots (var. Large Early Montgamet) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after storage (1960).

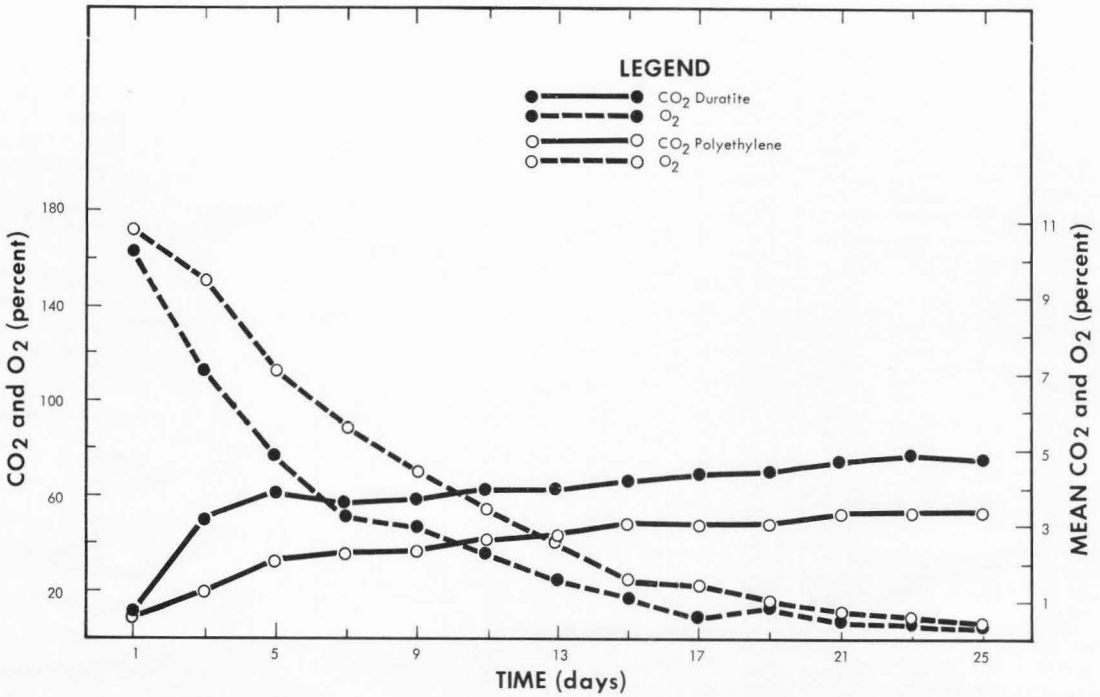

Figure 22. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of chemical treatments) in atmospheres surrounding apricots (var. Large Early Montgamet) stored at 40° F and 85 percent relative humidity for 25 days. Total CO_2 and O_2 percent represents the total of three bags of each kind under all treatments at alternate days. Mean CO_2 and O_2 percent represents the average of all the bags under all treatments at alternate days (1960).

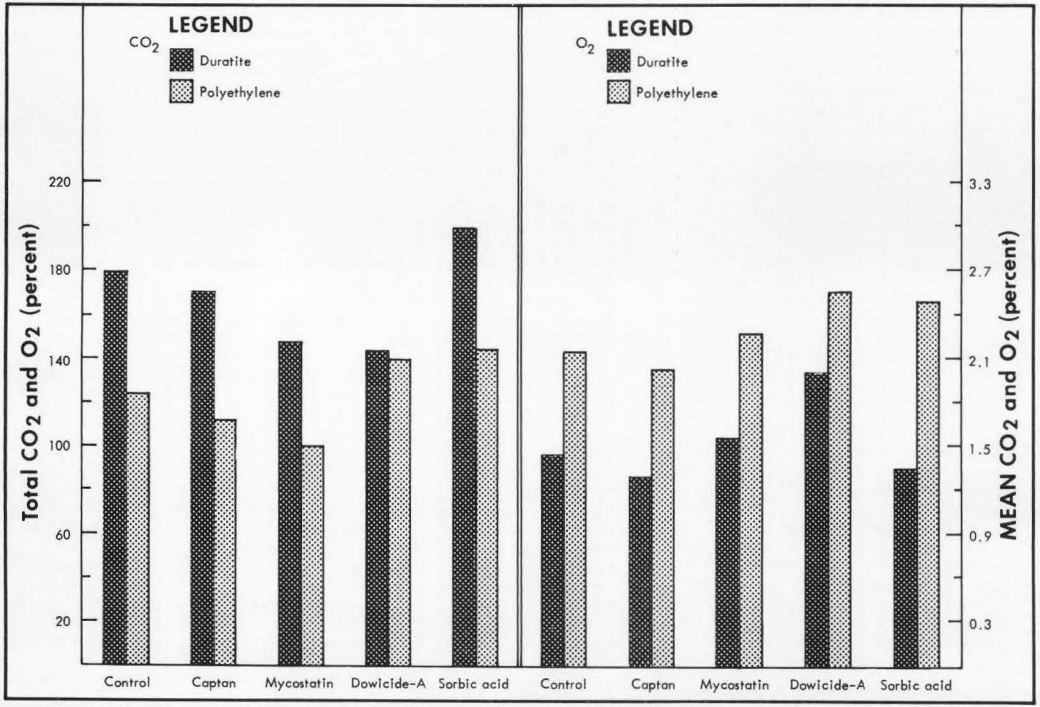

Figure 23. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of storage days) in atmospheres surrounding apricots (var. Large Early Montgamet) and stored at 40° F and 85 percent relative humidity for 25 days. Total CO_2 and O_2 percent represents the total of all observational days and three bags in each day. Mean CO_2 and O_2 percent represents the average of all the bags of all observational days under each treatment (1950).

behaved physiologically in the same manner (Figures 24 to 30, inclusive). The polyethylene film and prepackaging treatments with Captan and Mycostatin applied to apricots maintained lower levels of CO_2 and hence are more suitable in increasing the shelf life of the fruit than the Dowicide-A and sorbic acid treatments.

Because of its soft nature, the Moorpark variety deteriorated sooner (tables 4 and 5) than Large Early Montgamet, a firmer variety. Furthermore, Moorpark apricots deteriorated earlier in Duratite bags regardless of the chemical treatments because of higher levels of CO_2. This variety was more susceptible to CO_2 injury than Large Early Montgamet variety.

The variety Moorpark is softer than Large Early Montgamet at comparative stages of maturity. After about 15 days of chemical treatments and storage, Moorpark apricots showed splitting, mostly at the suture, irrespective of the treatments (Figure 31). The variety Large Early Montgamet did not show this storage disorder. The variety Moorpark may have a weaker middle lemella because of less deposition of salts of pectic acid. These pectic acid substances by the stimulatory action of chemicals on the enzyme pectinase are converted into soluble forms and hence the cells of the tissue concerned tend to separate from one another (Bonner and Galston, 1952).

Detailed analyses of variance for both the above mentioned varieties considering the effects of days elapsed storage, packaging films, and chemical treatments on the accumulation of CO_2 and O_2 are presented in appendix tables 13, 13a, 14, and 14a. These analyses show the amount of CO_2 given off and O_2 consumed by the fruits as measured on alternate days. The data indicate that CO_2 significantly increases until 16 days of storage and O_2 significantly decreases until 20 days,

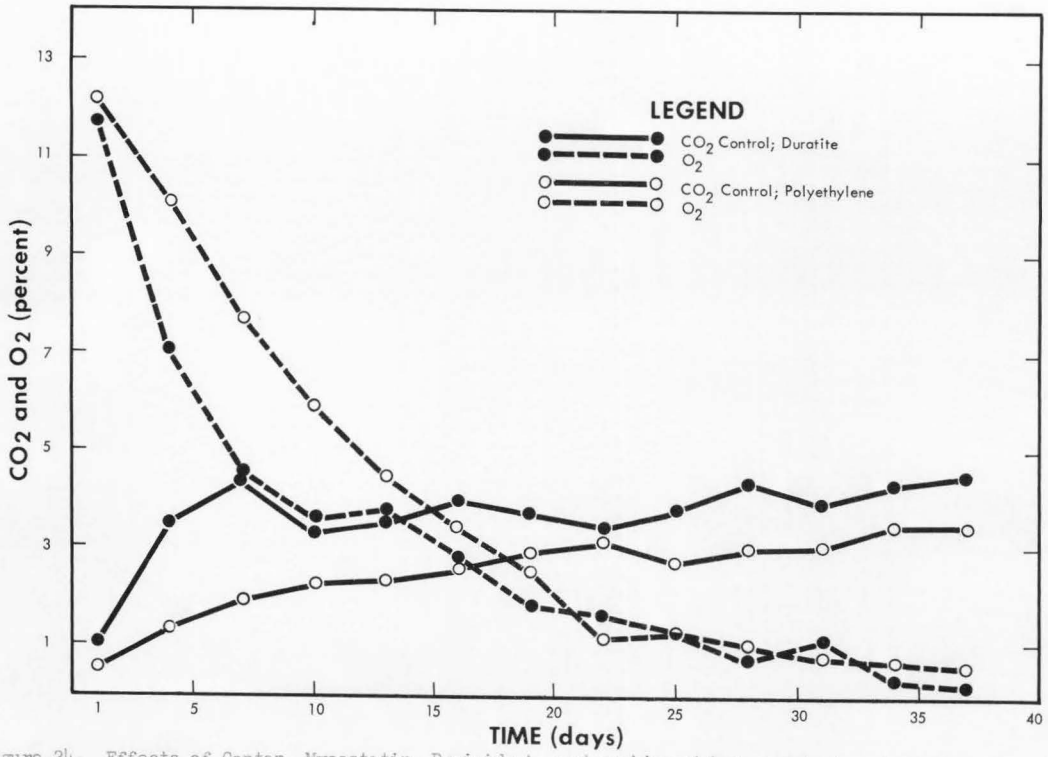

Figure 24. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid on respiratory behavior of apricots (var. Moorpark) packaged in Duratite and polyethylene films, and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage. (The curves presented in this figure serve as nontreated controls to be used for comparison with curves presented in Figures 25 to 28, inclusive, 1960).

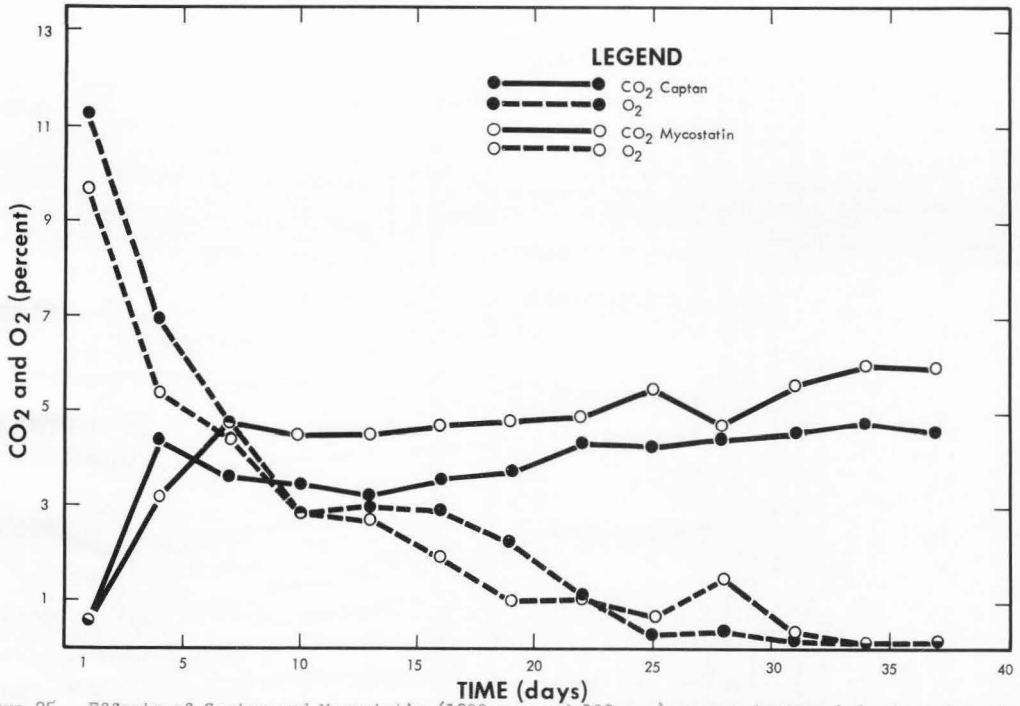

Figure 25. Effects of Captan and Mycostatin (1200 ppm and 100 ppm) on respiratory behavior of apricots (var. Moorpark) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

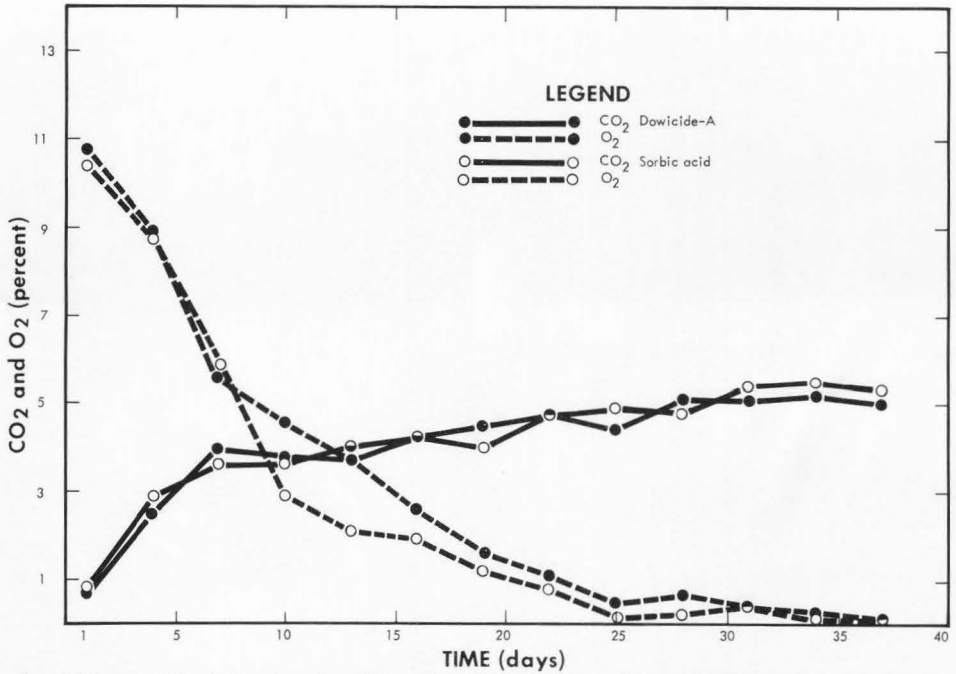

Figure 26. Effects of Dowicide-A and sorbic acid (1000 ppm and 5000 ppm) on respiratory behavior of apricots (var. Moorpark) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

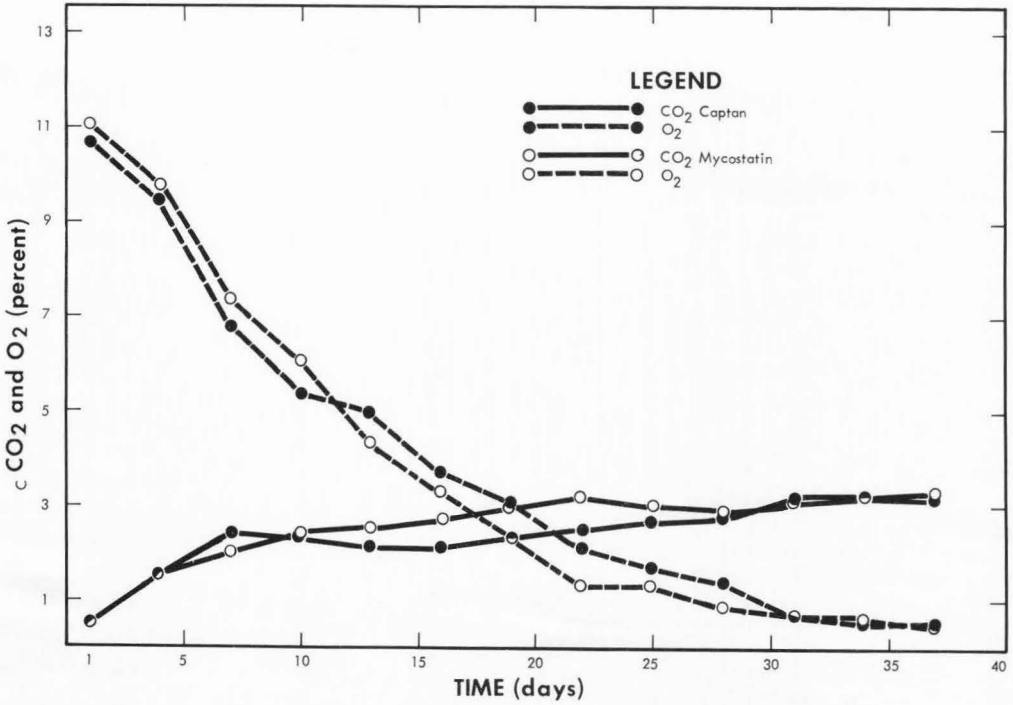

Figure 27. Effects of Captan and Mycostatin (1200 ppm and 100 ppm) on respiratory behavior of apricots (var. Moorpark) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

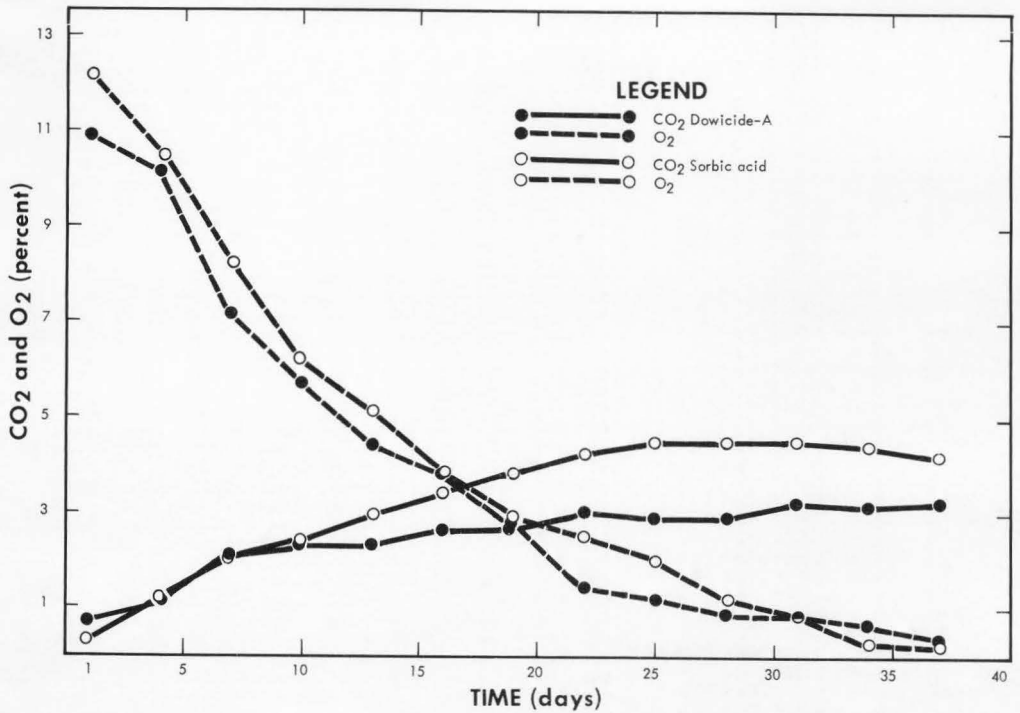

Figure 28. Effects of Dowicide-A and sorbic acid (1000 ppm and 5000 ppm) on respiratory behavior of apricots (var. Moorpark) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 37 days. Observations started 1 day after the storage (1960).

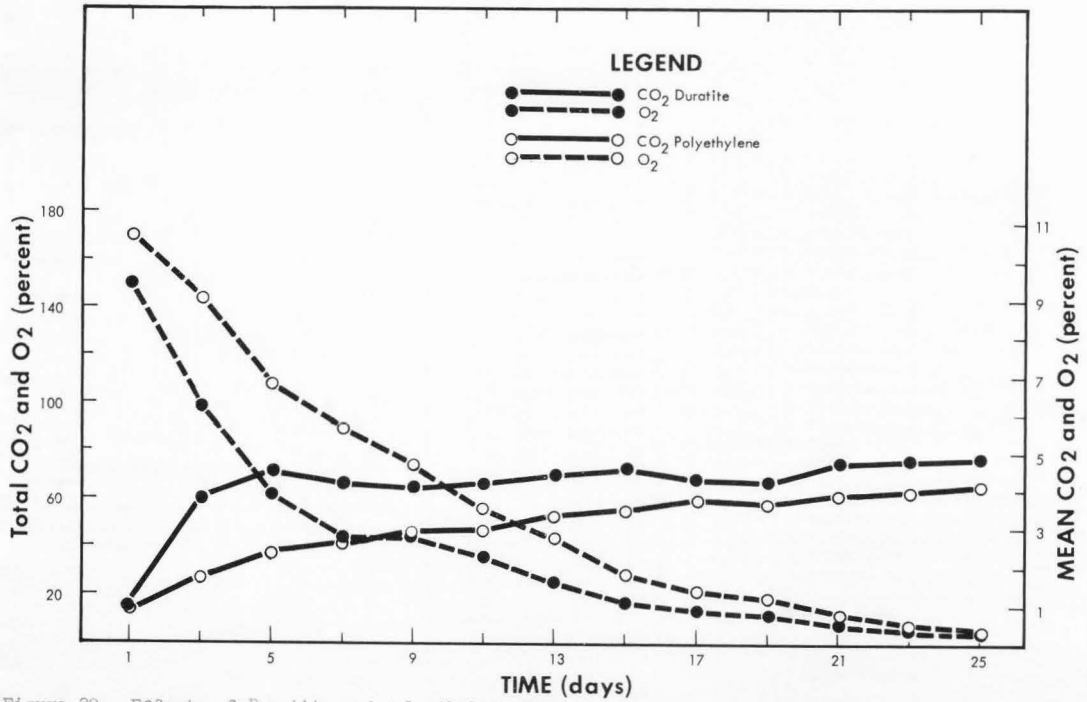

Figure 29. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of chemical treatments) in atmospheres surrounding apricots (var. Moorpark) and stored at 40° F and 85 percent relative humidity for 25 days. Total CO_2 and O_2 percent represents the total of three bags of each kind under all treatments at alternate days. Mean CO_2 and O_2 percent represents the average of all the bags under all treatments at alternate days (1960).

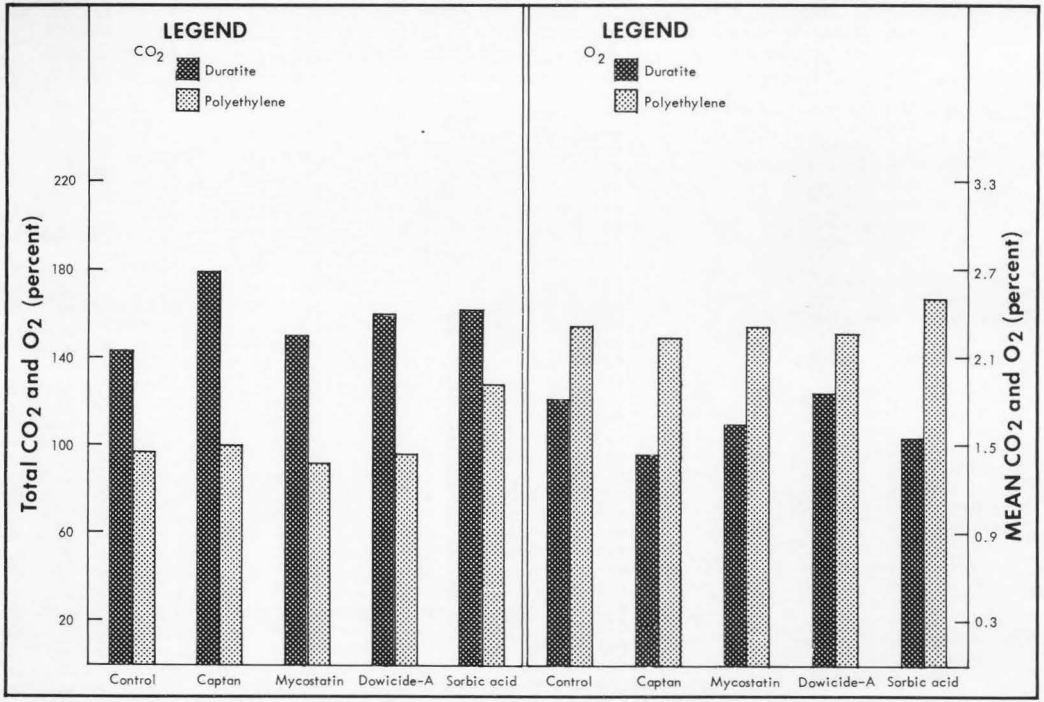

Figure 30. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of storage days) in atmospheres surrounding apricots (var. Moorpark) and stored at 40° F and 85 percent relative humidity for 25 days. Total CO_2 and O_2 percent represents the total of all observational days and three bags in each day. Mean CO_2 and O_2 percent represents the average of all the bags of all observational days under each treatment (1960).

Table 4. Effects of chemical treatments and packaging films on percentage of marketable fruits and fungus growth on apricots (var. Moorpark) of canning maturity[a] stored at 40° F and 85 percent relative humidity for 60 days (observations taken at 40, 50, and 60 days intervals, 1960)

Days in storage	Chemical	Concentration ppm	Packaging film: Duratite — No. of fruits	Duratite — Percent marketable fruits	Duratite — Fungi observed	Polyethylene — No. of fruits	Polyethylene — Percent marketable fruits	Polyethylene — Fungi observed
40	Control		54	28.37	Penicillium Rhizopus	56	18.07	Penicillium Rhizopus
	Captan	1200	60	70.91	Penicillium	55	40.00	Penicillium
	Mycostatin	100	60	63.16	Penicillium	47	53.19	Penicillium
	Dowicide-A	1000	55	11.66	Penicillium	59	38.98	Penicillium
	Sorbic acid	5000	57	10.66	Penicillium	63	39.68	Penicillium
50	Control		57	1.75	Penicillium Rhizopus Alternaria	59	5.08	Penicillium Rhizopus Alternaria
	Captan	1200	63	4.75	Penicillium	60	26.66	Penicillium
	Mycostatin	100	66	0.00	Penicillium	59	0.00	Penicillium
	Dowicide-A	1000	63	9.52	Penicillium	63	15.87	Penicillium
	Sorbic acid	5000	57	0.00	Penicillium	54	1.85	Penicillium
60	Control		60	0.00	Penicillium Rhizopus Alternaria	60	0.00	Penicillium Rhizopus
	Captan	1200	60	0.00	Penicillium	60	0.00	Penicillium
	Mycostatin	100	57	0.00	Penicillium	57	0.00	Penicillium
	Dowicide-A	1000	60	0.00	Penicillium	60	0.00	Penicillium
	Sorbic acid	5000	60	0.00	Penicillium Rhizopus Alternaria	60	0.00	Penicillium Rhizopus Alternaria

[a]Canning maturity refers to the stage of firm ripe apricots at which they are usually processed by canning.

Table 5. Effects of chemical treatments and packaging films on percentage of marketable fruits and fungus growth on apricots (var. Moorpark) of shipping maturity[a] stored at 40° F and 85 percent relative humidity for 60 days (observations taken at 40, 50, and 60 days intervals, 1960)

Days in storage	Chemical	Concentration ppm	Packaging film: Duratite — No. of fruits	Duratite — Percent marketable fruits	Duratite — Fungi observed	Polyethylene — No. of fruits	Polyethylene — Percent marketable fruits	Polyethylene — Fungi observed
40	Control		53	33.96	Penicillium Rhizopus	57	28.07	Penicillium Rhizopus
	Captan	1200	60	18.33	Penicillium	55	43.64	Penicillium
	Mycostatin	100	60	18.33	Penicillium	57	52.63	Penicillium
	Dowicide-A	1000	59	79.66	Penicillium	63	52.38	Penicillium
	Sorbic acid	5000	57	68.44	Penicillium Rhizopus	59	44.7	Penicillium
50	Control		57	1.75	Penicillium Rhizopus Alternaria	59	1.17	Penicillium Rhizopus Alternaria
	Captan	1200	63	9.52	Penicillium	60	33.33	Penicillium
	Mycostatin	100	66	0.00	Penicillium	60	1.66	Penicillium
	Dowicide-A	1000	58	10.05	Penicillium	63	25.39	Penicillium
	Sorbic acid	5000	63	3.45	Penicillium Rhizopus	54	9.26	Penicillium
60	Control		60	0.00	Penicillium Rhizopus Alternaria	60	0.00	Penicillium Rhizopus
	Captan	1200	60	0.00	Penicillium	57	1.66	Penicillium
	Mycostatin	100	57	0.00	Penicillium	60	0.00	Penicillium
	Dowicide-A	1000	60	0.00	Penicillium	60	0.00	Penicillium
	Sorbic acid	5000	60	0.00	Penicillium Rhizopus Alternaria	60	0.00	Penicillium Rhizopus Alternaria

[a]Shipping maturity refers to the stage of mature green apricots at which they are usually shipped to distant markets.

Figure 31. Effects of chemical treatments and packaging films on splitting of apricots (var. Moorpark) stored at 40° F and 85 percent relative humidity. Splitting character was observed 20 days after the chemical treatments (1960).

after which both the gases remain fairly constant for 37 days. Polyethylene film maintains significantly lower levels of CO_2 and higher O_2 than Duratite film which maintains higher levels of CO_2 and lower O_2. As far as chemical treatments are concerned, Captan and Mycostatin combined with polyethylene film maintained significantly lower levels of CO_2 and higher O_2 than the other chemicals.

Peaches (var. Elberta)

In experiments with the Elberta variety of peaches it was found that respiration during the first 24 hours consumed 13 to 14 percent of the oxygen to accumulate 2 to 3 percent CO_2 (Figures 32 to 40). It is a well known fact that for each molecule of sugar broken down, six molecules of oxygen are required to give six molecules each of CO_2 and H_2O. Therefore, one molecule of O_2 is needed to produce one molecule of CO_2. Bonner and Galston (1952) have shown this in the following equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}.$$

The results obtained in the above mentioned peach storage experiments do not seem to agree with the postulated equation. Thus, perhaps because of higher concentration of O_2 inside the bags, the fruit might have respired faster and, due to high pressure of atmosphere inside the bags, the air must have diffused out of the bags.

After the level of CO_2 increased and that of O_2 decreased, the further rise of CO_2 level inside the bags was slow because of inhibition of respiration by lowered O_2 and increased CO_2 concentrations. In general, the higher the concentration of CO_2, the more the respiration rate is depressed (Kidd and West, 1927; and Van Doren, 1939, working on apples). It can be noticed in Figure 32 that polyethylene bags keep the

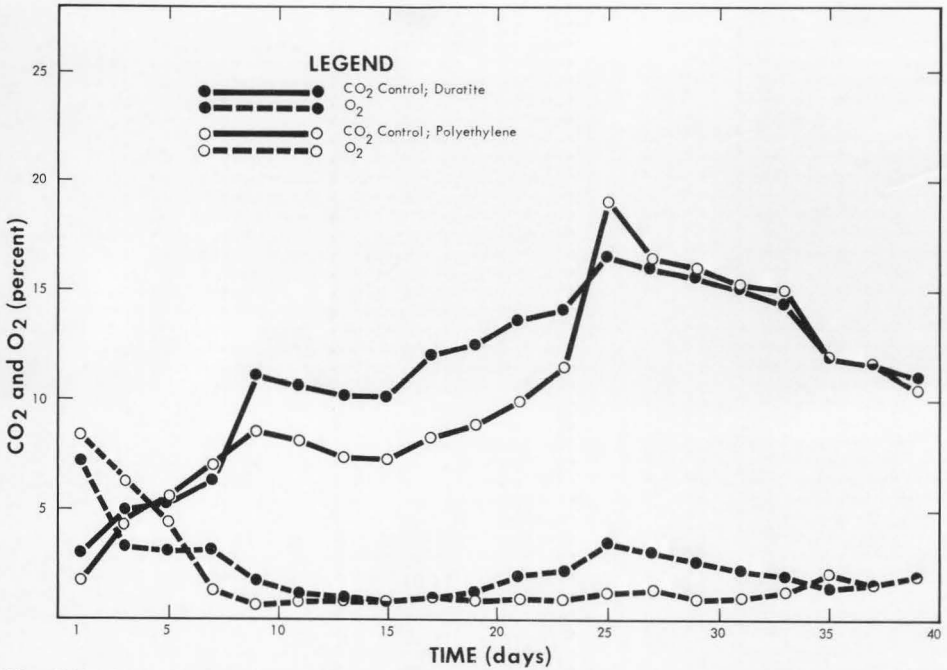

Figure 32. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid on the respiratory behavior of peaches (var. Elberta) packaged in Duratite and polyethylene films and stored at 40° F and 85 percent relative humidity for 39 days. (The curves presented in this figure serve as nontreated controls to be used for the comparison with curves presented in Figures 33 to 40, inclusive, 1960).

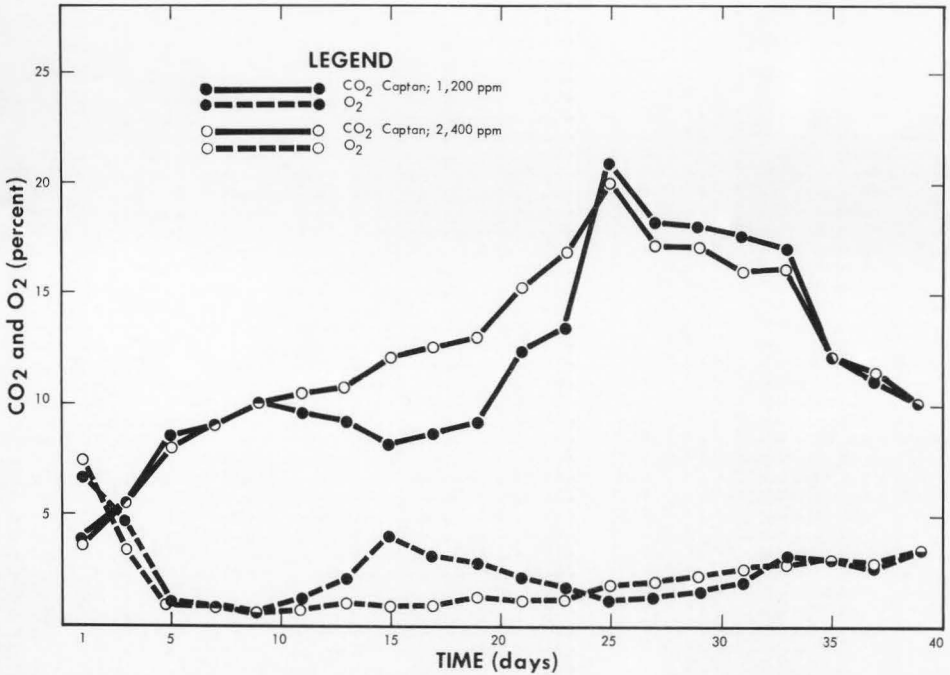

Figure 33. Effects of Captan (1200 ppm and 2400 ppm) on the respiratory behavior of peaches (var. Elberta) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

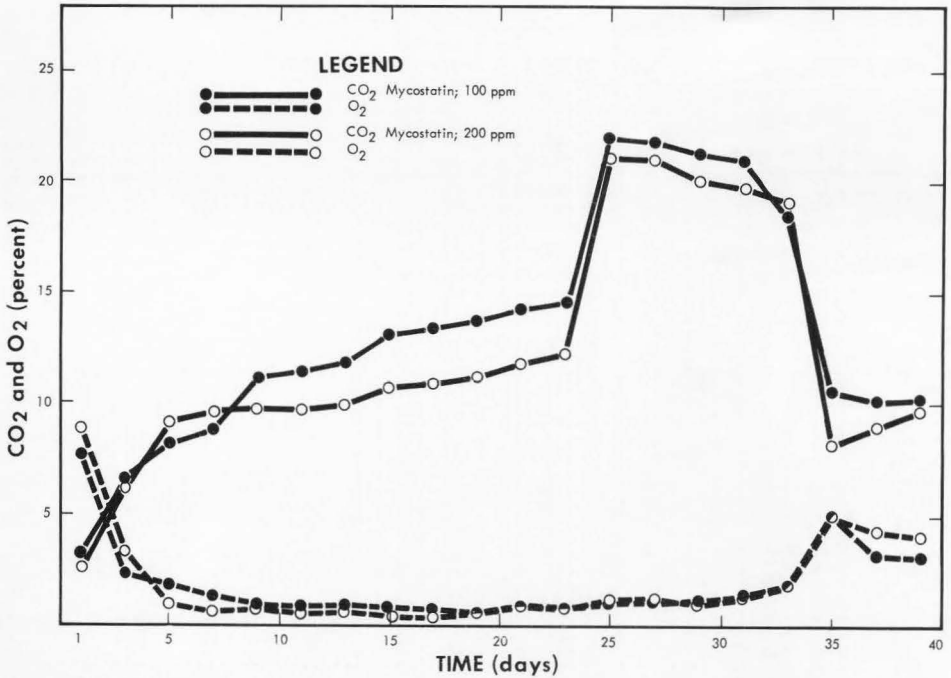

Figure 34. Effects of Mycostatin (100 ppm and 200 ppm) on the respiratory behavior of peaches (var. Elberta) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

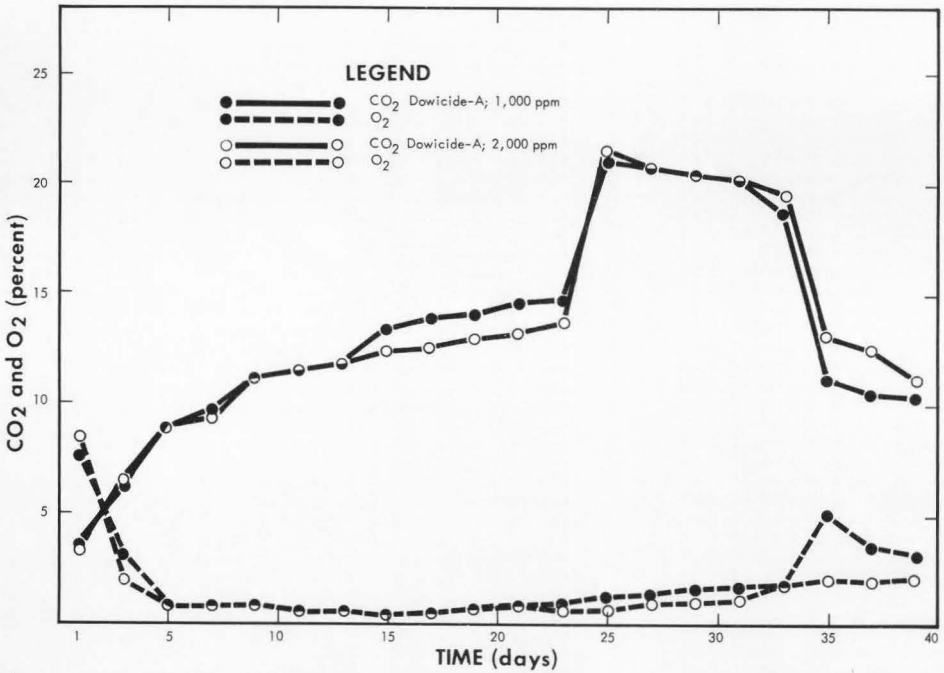

Figure 35. Effects of Dowicide-A (1000 ppm and 2000 ppm) on the respiratory behavior of peaches (var. Elberta) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

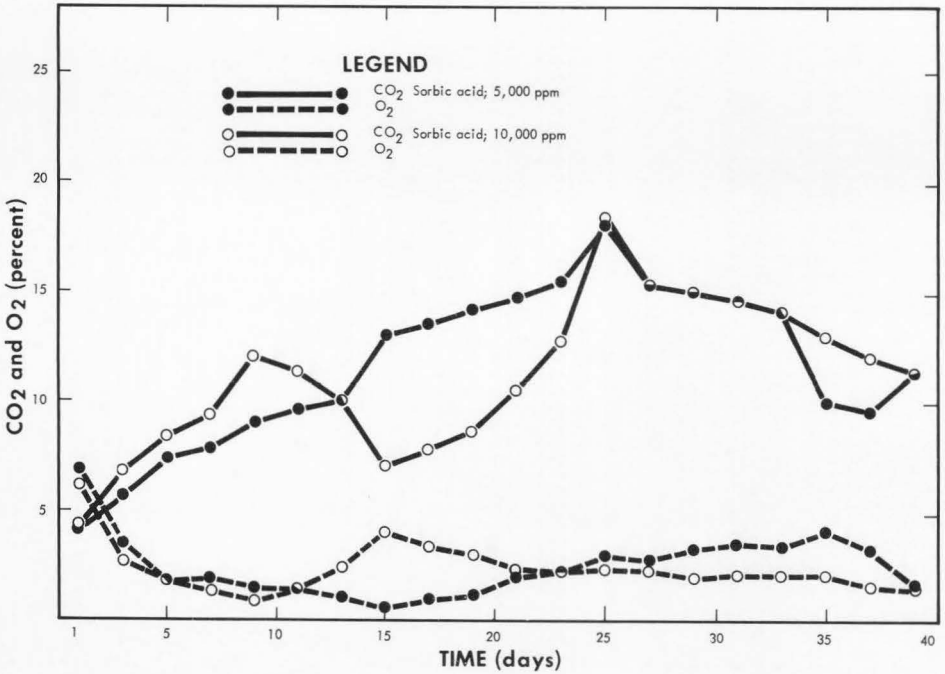

Figure 36. Effects of sorbic acid (5000 ppm and 10,000 ppm) on respiratory behaviro of peaches (var. Elberta) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

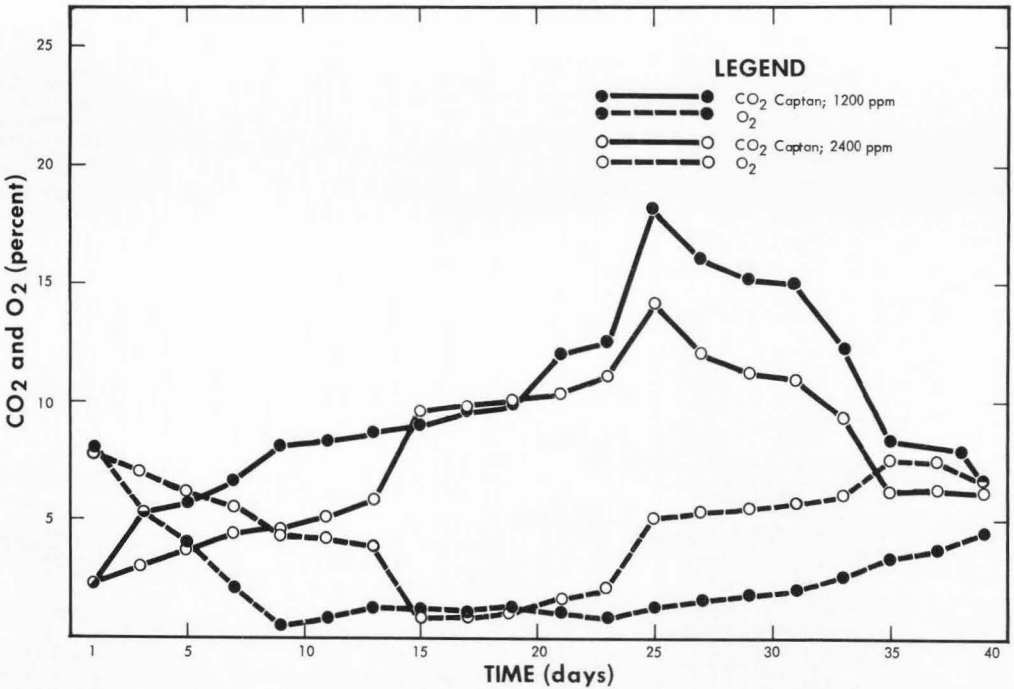

Figure 37. Effects of Captan (1200 ppm and 2400 ppm) on respiratory behavior of peaches (var. Elberta) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

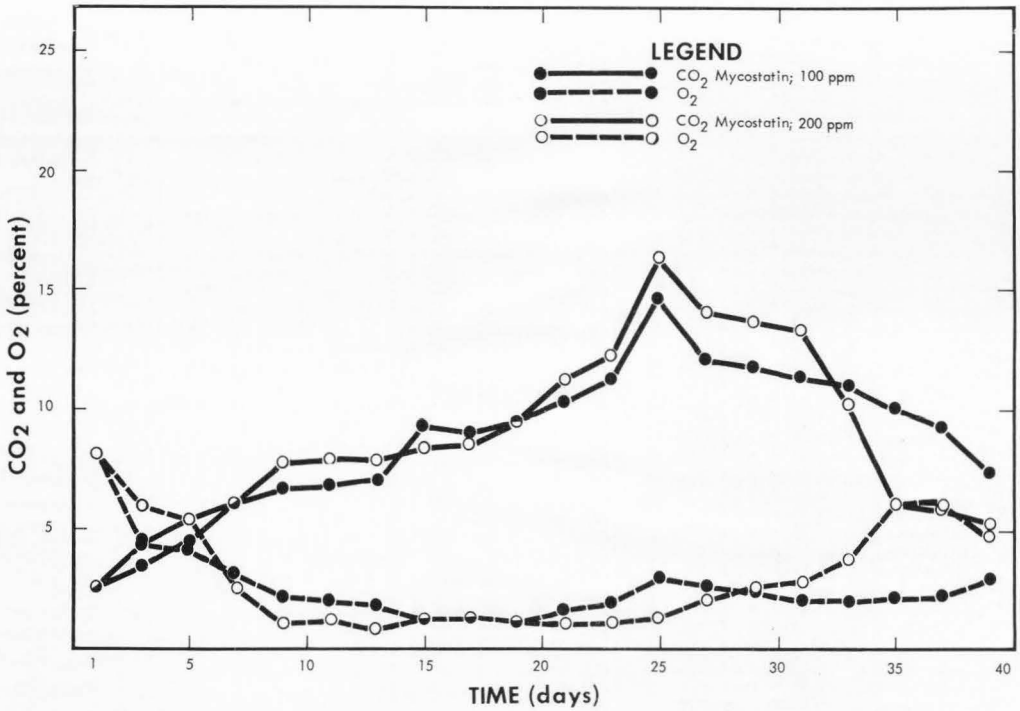

Figure 38. Effects of Mycostatin (100 ppm and 200 ppm) on the respiratory behavior of peaches (var. Elberta) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

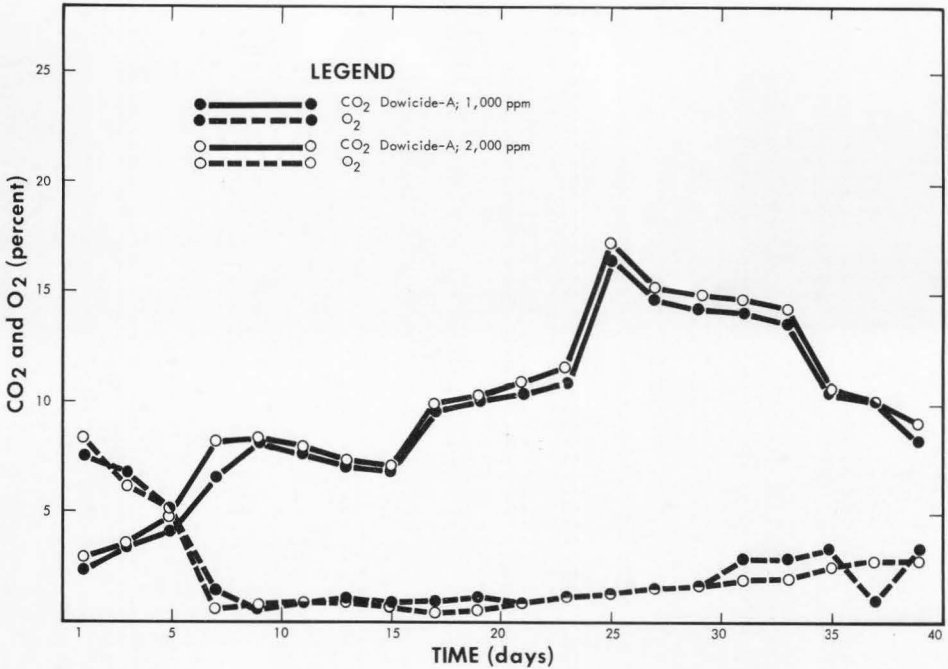

Figure 39. Effects of Dowicide-C (1000 ppm and 2000 ppm) on the respiratory behavior of peaches (var. Elberta) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

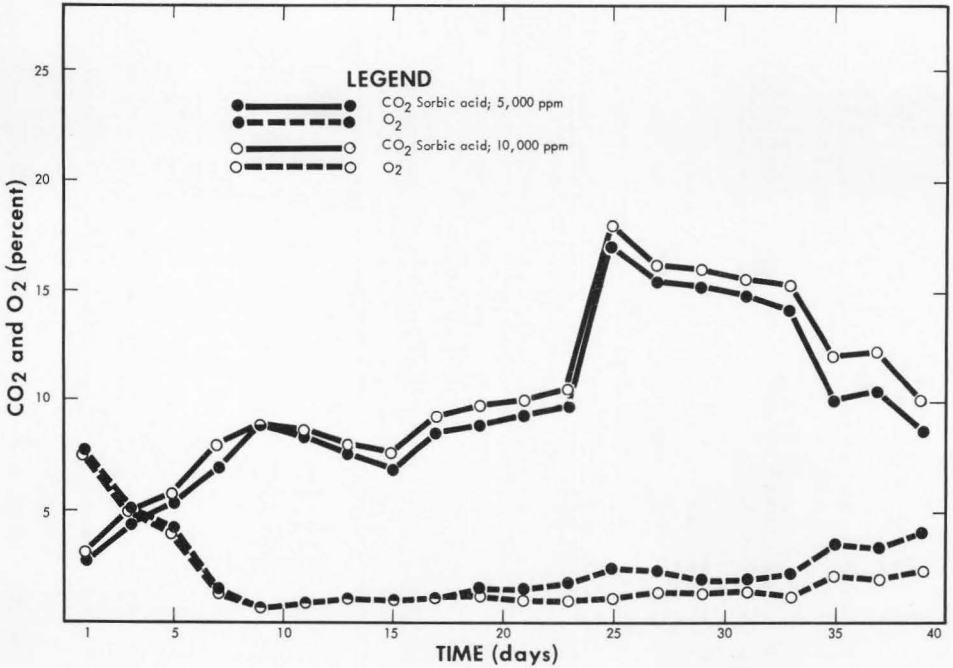

Figure 40. Effects of sorbic acid (5000 ppm and 10,000 ppm) on the respiratory behavior of peaches (var. Elberta) packaged in polyethylene film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 1 day after the storage (1960).

concentration of CO_2 lower than Duratite bags.

Looking at Figures 33 to 36 inclusive, it may be noted that the higher chemical concentrations of Mycostatin (200 ppm), Dowicide-A (2000 ppm), and sorbic acid (10,000 ppm) kept the CO_2 level lower by inhibiting respiration when compared with their lower concentrations. In contrast to this, Captan had more of an inhibiting effect on respiration at its lower concentration (1200 ppm). The data indicate that chemical treatments can stimulate or inhibit respiration of the fresh fruit. The results obtained by Michell and Marth, 1944, working on fruits in general; Gerhardt and Allmendinger, 1945, working on apples, pears, and sweet cherries; and Woodruff and Crandall, 1958, working on apples, agree with the results of this study.

Polyethylene bags maintained significantly lower CO_2 levels than Duratite bags (Figures 37 to 40, inclusive). The lower concentrations of Captan and Mycostatin (1200 ppm and 100 ppm, respectively) were most effective in lowering respiration of the fruit. The higher concentrations of Dowicide-A and sorbic acid used in treatments were most effective in lowering respiration of peaches. The respiratory curve of the higher concentration (2400 ppm) of the Captan is not consistent and is fluctuating at various time intervals. This may be because the higher concentrations of Captan may have drastic effects on the enzymic systems responsible for respiration, which are affected at times by the action of Captan. It is quite probable that the respiration follows different pathways in which different enzyme systems are acting as the storage period progresses. It is also quite possible that the action of Captan on one enzyme system (during the first few days) may be stimulating and then be inhibiting on another enzyme system that takes

over at a later storage stage. Or the effectiveness of Captan may decrease with the advancement of storage time and inhibited systems may be activated again (Harrow and Mazur, 1958).

At certain terminating points, a slight rise in curves is noticed. This rise cannot be accounted for by the respiratory rise of the fruit. On the other hand, it may be due to the reason that when fruit becomes weak by exhausting the stored food material in the process of respiration, cells become loose due to the changes in pectic substances and leave a suitable place for the organisms (fungi) to attack the fruit. Therefore, the rise in the last point of the curves may be due to the respiration contribution of fungal organisms which may have originated in the weak fruit and were not noticed visually at the time of examinations.

Summarizations of the marketable quality of the fruit are presented in table 6. After 20 days of storage, 100 percent of the fruit was free of fungi in Captan treatments, whereas Dowicide-A, Mycostatin, and sorbic acid were progressively less effective. DiMarco (1959) and Cooper (1961) observed similar results in studies of strawberries and cherries. Controls (nontreated) were 100 percent infected by fungi. Even after 40 days of storage Captan was still the best in inhibiting the fungus growth on the fruits. The appearance of the experimental fruit can be seen in Figure 41. Controls and sorbic acid treated fruit were all invaded by the fungi. Increased dosage in each treatment has little or no significant effect in preventing spoilage. Significant differences among the chemical treatments used to inhibit the fungal growth are shown in appendix table 15. Rhizopus, Alternaria, and Monilinia are completely inhibited or killed by Captan, Dowicide-A, Mycostatin, and sorbic acid treatments except that a little Monilinia

Table 6. Effects of chemical treatments and Duratite packaging film on percentage of marketable fruits and fungus growth on peaches (var. Elberta); the peaches inoculated with fungi (penicillium, Rhizopus, Alternaria, and Monilinia species) prior to chemical treatments and packaging and then stored at 40° F and 85 percent relative humidity for 40 days (observations taken at 20, 30, and 40 days intervals, 1960)

Days in storage	Chemical	Concentration ppm	No. of fruits	Percent marketable fruits	Fungi observed
20	Control		45	0.00	Penicillium, Rhizopus
	Captan	1200	45	100.00	
		2400	45	100.00	
	Mycostatin	100	45	80.00	Penicillium
		200	45	86.00	Penicillium
	Dowicide-A	1000	45	86.00	Penicillium
		2000	45	97.77	Penicillium
	Sorbic acid	5000	45	44.44	Penicillium
		10000	45	44.44	Penicillium
30	Control		45	0.00	Penicillium, Rhizopus
	Captan	1200	45	86.00	Penicillium
		2400	45	53.33	Penicillium
	Mycostatin	100	45	15.55	Penicillium
		200	45	15.55	Penicillium
	Dowicide-A	1000	45	4.44	Penicillium
		2000	45	17.77	Penicillium
	Sorbic acid	5000	45	2.22	Penicillium, Rhizopus
		10000	45	0.00	Penicillium, Rhizopus
40	Control		45	0.00	Penicillium, Rhizopus Alternaria, Monilinia
	Captan	1200	45	66.66	Penicillium
		2400	45	60.00	Penicillium
	Mycostatin	100	45	4.44	Penicillium
		200	45	4.44	Penicillium
	Dowicide-A	1000	45	0.00	Penicillium
		2000	45	0.00	Penicillium
	Sorbic acid	5000	45	0.00	Penicillium, Rhizopus
		10000	45	0.00	Penicillium, Rhizopus Monilinia

Figure 41. Effects of chemical treatments and Duratite film on physical quality and fungal growth on peaches (var. Elberta) stored at 40° F and 85 percent relative humidity (photographed 40 days after chemical treatments). Top row = lower chemical concentrations; bottom row = higher chemical concentrations. Left to right: A = Captan, 1200 ppm and 2400 ppm; B = Dowicide-A, 1000 ppm and 2000 ppm; C = Mycostatin, 100 ppm and 200 ppm; D = sorbic acid, 5000 ppm and 10,000 ppm (1960).

growth was observed in the sorbic acid treatment. Penicillium was the only organism which was not affected by the chemical dips, although it was inhibited for some time (table 6).

In the statistical analysis presented in appendix tables 16 and 16a, the amounts of CO_2 given off and O_2 consumed by the fruits (measured on alternate days) are shown. The data indicate that CO_2 increases significantly and O_2 decreases significantly during the first 8 days of storage in both polyethylene and Duratite films; after this both gas levels remained fairly constant. Polyethylene film maintains significantly lower levels of CO_2 and higher levels of O_2 than Duratite film. All chemical treatments combined with polyethylene film maintained lower levels of CO_2 and higher O_2 than the same chemical treatments combined with Duratite film. The significant differences between polyethylene and Duratite films in the accumulation of CO_2 and O_2 are shown graphically in Figures 42 to 44, inclusive.

Pears (var. Bartlett)

The respiration rate of pears is slower than that of apricots and peaches. Figure 45 shows the slow increase in the level of CO_2 and slow decrease in the level of O_2 with storage time. It took 15 days for the CO_2 to change from 0.03 percent to 3.5 percent and for the O_2 to change from 11.5 percent to 3 percent.

Theoretically, the respiration of fruit in closed containers with no O_2 and accumulated CO_2 is completely inhibited. Anaerobic respiration just prior to complete inhibition can result in the production of alcohols within the fruit. If the percentage of O_2 is kept constant at a desirable level by introducing small amounts of O_2 as needed, the

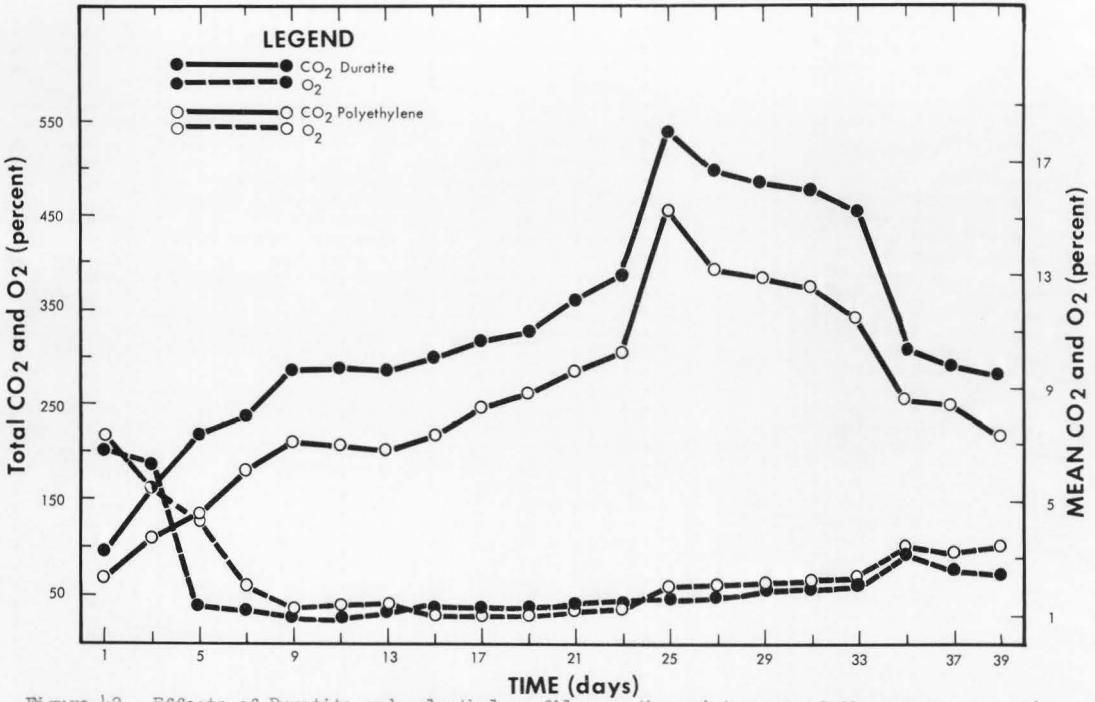

Figure 42. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of chemical treatments) in atmospheres surrounding peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 39 days. Total CO_2 and O_2 percent represents the total of three bags of each kind under all treatments at alternate days. Mean CO_2 and O_2 percent represents the average of all the bags in all treatments at alternate days (1960).

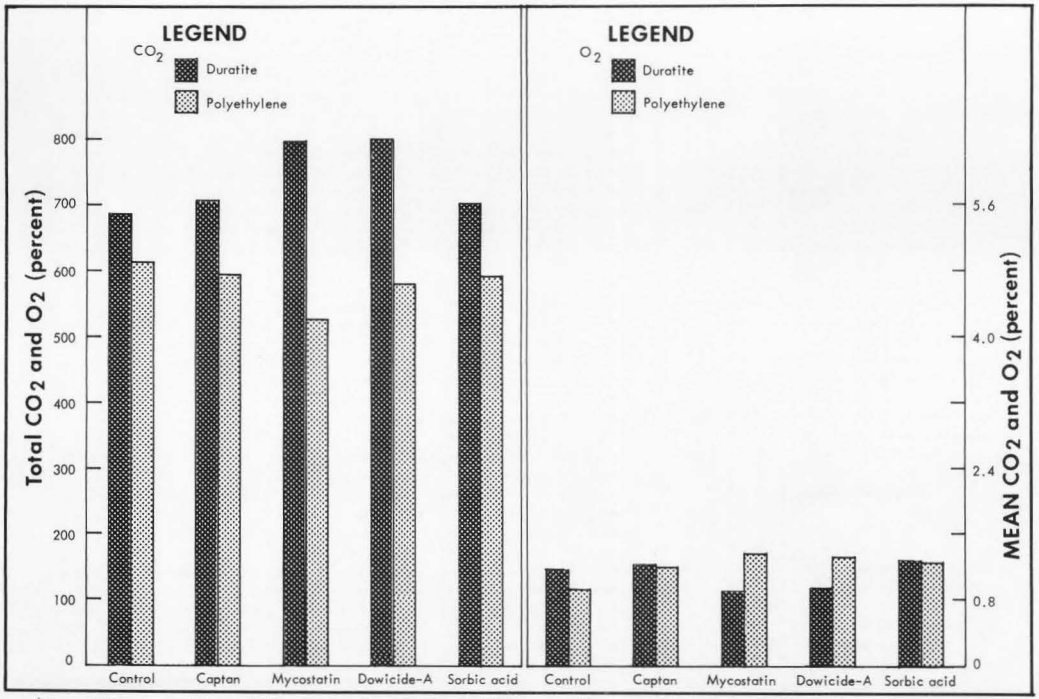

Figure 43. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of storage days) in atmospheres surrounding peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 39 days. Total CO_2 and O_2 percent represents the total of all observational days and three bags in each day from lower concentrations of the treatments (Captan, 1200 ppm; Mycostatin, 100 ppm; Dowicide-A, 1000 ppm; and sorbic acid, 5000 ppm). Mean CO_2 and O_2 percent represents the average of all the bags in all observational days under each treatment (1960).

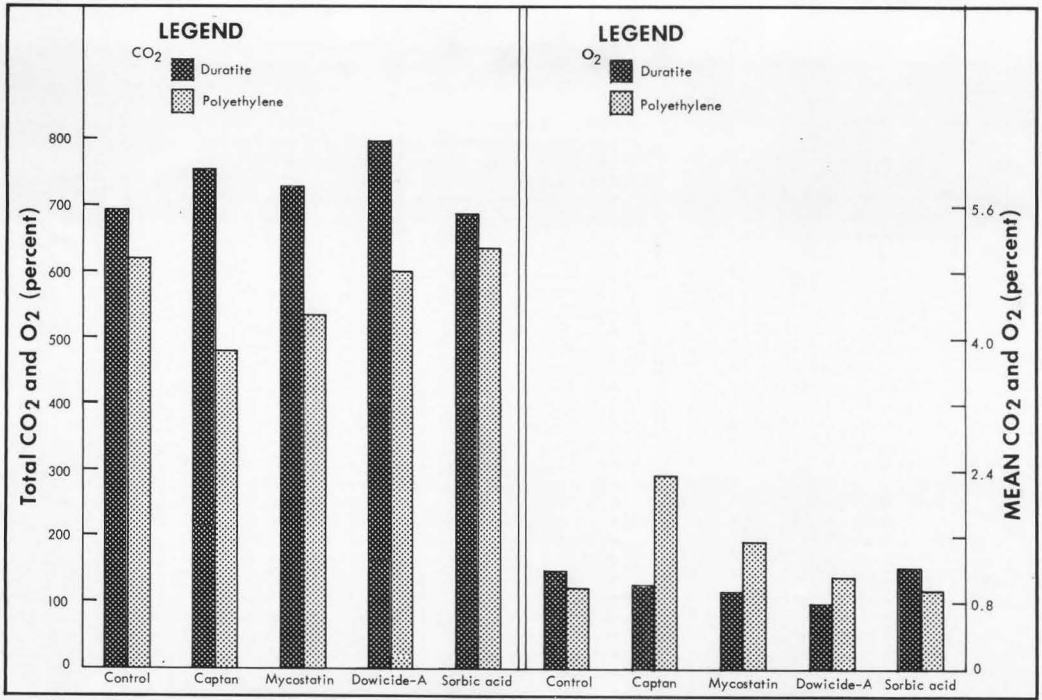

Figure 44. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of storage days) in atmospheres surrounding peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 39 days. Total CO_2 and O_2 percent represents the total of all observational days and three bags in each day from higher concentrations of the treatments (Captan, 2400 ppm; Mycostatin, 200 ppm; Dowicide-A, 2000 ppm; and sorbic acid, 10,000 ppm). Mean CO_2 and O_2 percent represents the average of all the bags in all observational days under each treatment (1960).

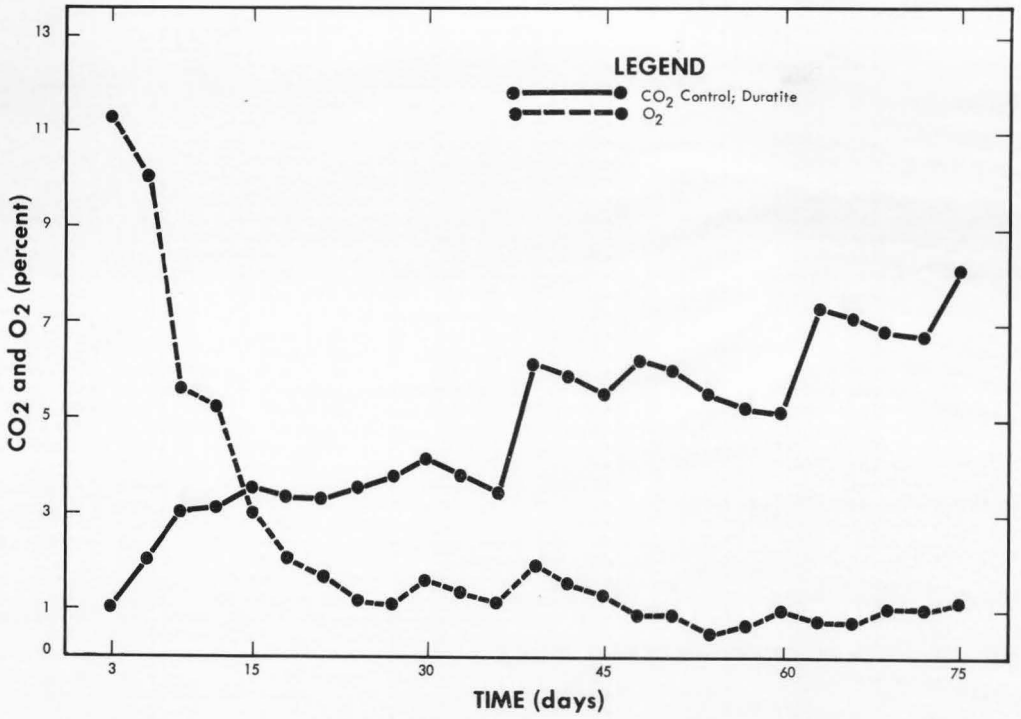

Figure 45. Effects of Captan, Mycostatin, and sorbic acid on the respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 75 days. (The curves presented in this figure serve as nontreated controls to be used for the comparison with curves presented in Figures 46 to 48, inclusive, 1960).

CO_2 would probably also remain fairly constant. The film in this experiment was performing a desirable function of introducing a constant supply of O_2 while allowing limited amounts of CO_2 to pass outward. From the twenty-fifth to the seventy-fifth day of storage, oxygen remained at about 1 percent while the CO_2 level continued to rise with elapsed storage time (Figures 46 to 48, inclusive). The supply of O_2 passing through the film was sufficient to maintain respiration without the production of undesirable anaerobic alcoholic products. These results agree with those obtained by Ryall and Uota (1955) in studies of apples.

The patterns of respiratory curves obtained with the chemical treatments, Captan, Mycostatin, and sorbic acid (Figures 46 to 48, inclusive) are nearly the same as that of the nontreated controls already discussed. But there are slight differences in the maintenance of CO_2 and O_2 levels. The higher concentrations of the chemical treatments maintained lower levels of CO_2 than the lower chemical concentrations. The sorbic acid treatment maintained a higher level of CO_2 than Captan, Mycostatin, and the controls. In the beginning of the experiment with sorbic acid at the 5000 ppm level, the CO_2 was lower than that of the 10,000 ppm treatment. But after about 45 days of storage the higher concentration showed an effect in inhibiting the rise of CO_2 level. It was concluded that there was not much difference between the two concentrations.

Ordinarily, pears tend to develop internal disorders when stored at temperatures as low as 32° F. We have found that internal breakdown is avoided if pears are stored at a temperature of 40° F in controlled atmospheres having proper proportions of CO_2 and O_2. Some of the chemical treatments such as Captan and Mycostatin also helped in preventing the internal breakdown of pears in combination with the Duratite

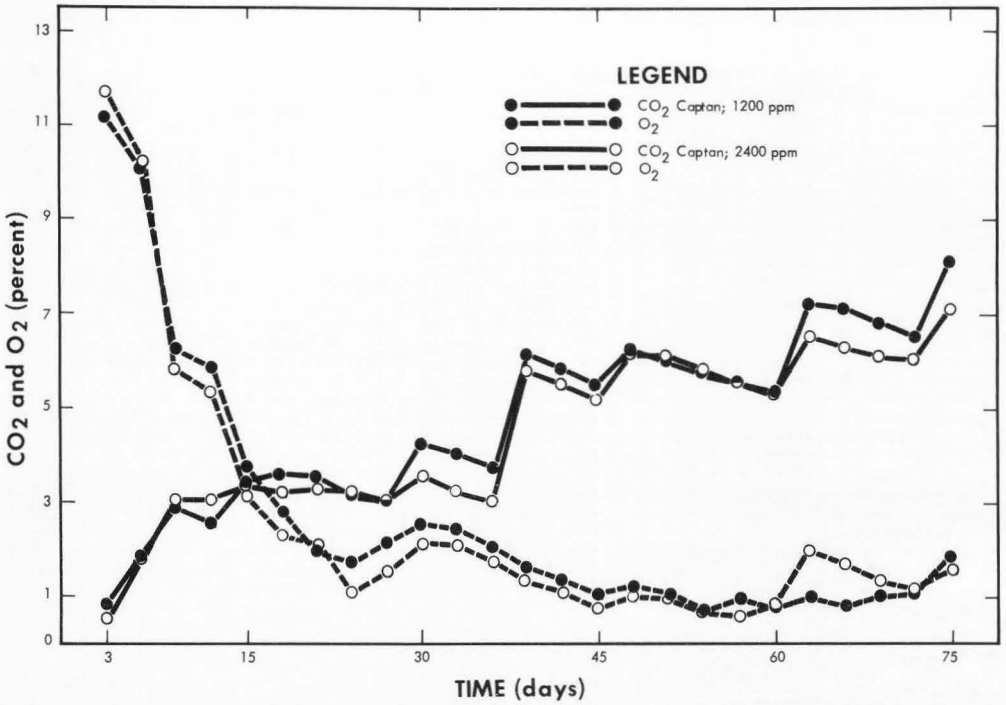

Figure 46. Effects of Captan (1200 ppm and 2400 ppm) on the respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 75 days. Observations started 3 days after the storage (1960).

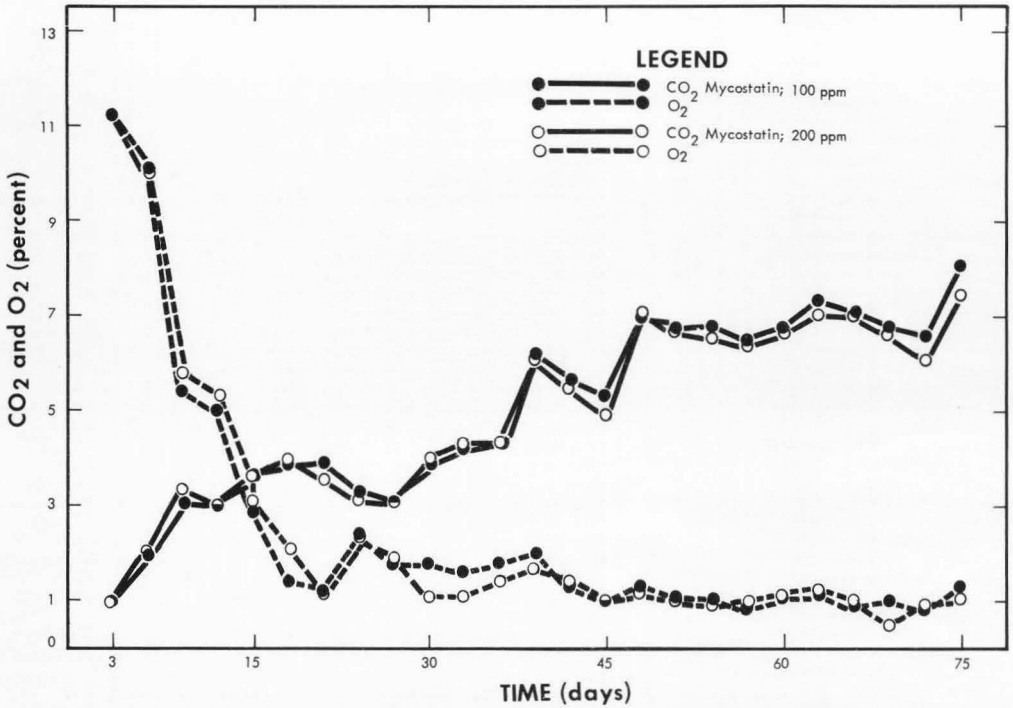

Figure 47. Effects of Mycostatin (100 ppm and 200 ppm) on respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 75 days. Observations started 3 days after the storage (1960).

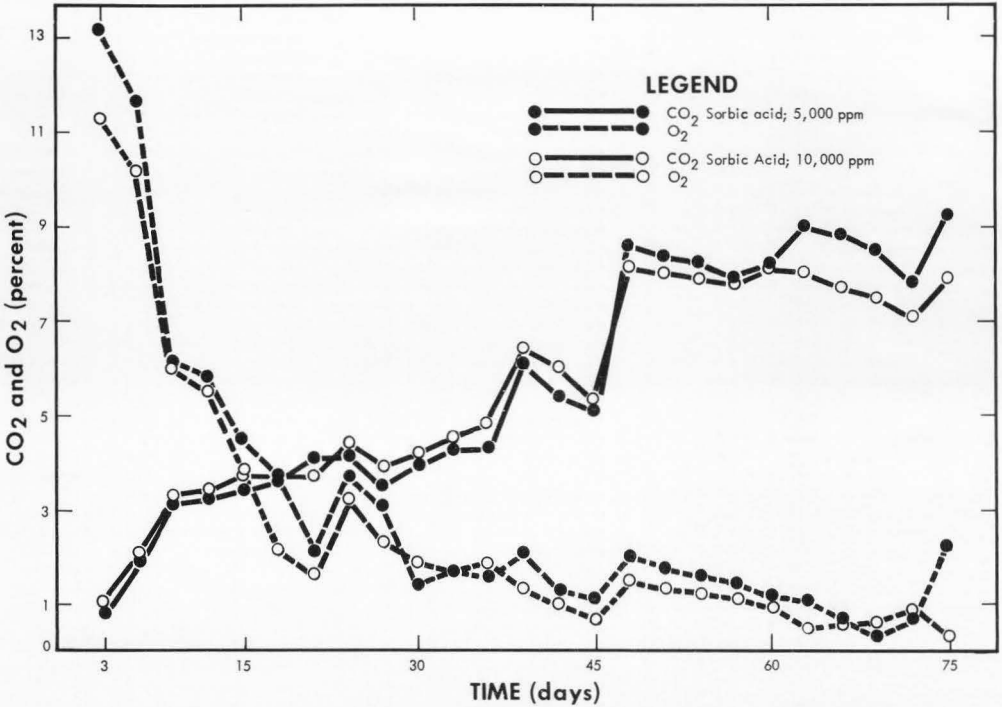

Figure 48. Effects of sorbic acid (5000 ppm and 10,000 ppm) on respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 75 days. Observations started 3 days after the storage (1960).

bags maintaining a modified atmosphere at 40° F (Figure 49). The results of this experiment agree with those of Phillips (1939) and Smock and Van Doren (1941) in studies with apples. Pears can be stored for 75 days under such conditions without much damage to the fruit. Pears were also kept at 40° F and 85 percent relative humidity after the application of Captan and Mycostatin (1200 ppm and 100 ppm) treatments without packaging in film bags. After 46 days of storage it was observed that treated fruits were in fairly good condition whereas controls (nontreated) were all dried and discolored (Figure 50). The reason for this result is unknown but it is postulated that the chemicals may have inhibited transpiration and drying of skin by altering the permeability of the outer cell membranes to the passage of water.

Observations on the marketable quality of the experimental pears are presented in table 7. It was observed that after 30 days of storage all treatments were significantly superior to the controls. But there was no significant difference among chemical treatments and their relative concentrations (appendix table 17). The same statistical pattern was observed after 30, 45, and 60 days of storage. It can be concluded from this data that the concentrations of Captan and Mycostatin used have longer range effects in protecting the fruits from fungi than Dowicide-A and sorbic acid (table 7). These results are also illustrated in Figure 51. Results obtained in 1961 are presented in Figures 52 to 54, inclusive. These results are somewhat similar to those obtained in 1960.

The analysis of variance presented in appendix tables 18 and 18a shows that the amount of CO_2 given off and O_2 consumed by the fruits measured on alternate days. There is a significant rise in level of

Figure 49. Effects of packaging film and modified atmosphere on internal breakdown of pears (var. Bartlett) stored at 40° F and 85 percent relative humidity (photographed 70 days after storage). Top row = unpackaged controls; bottom row = modified atmosphere (1960).

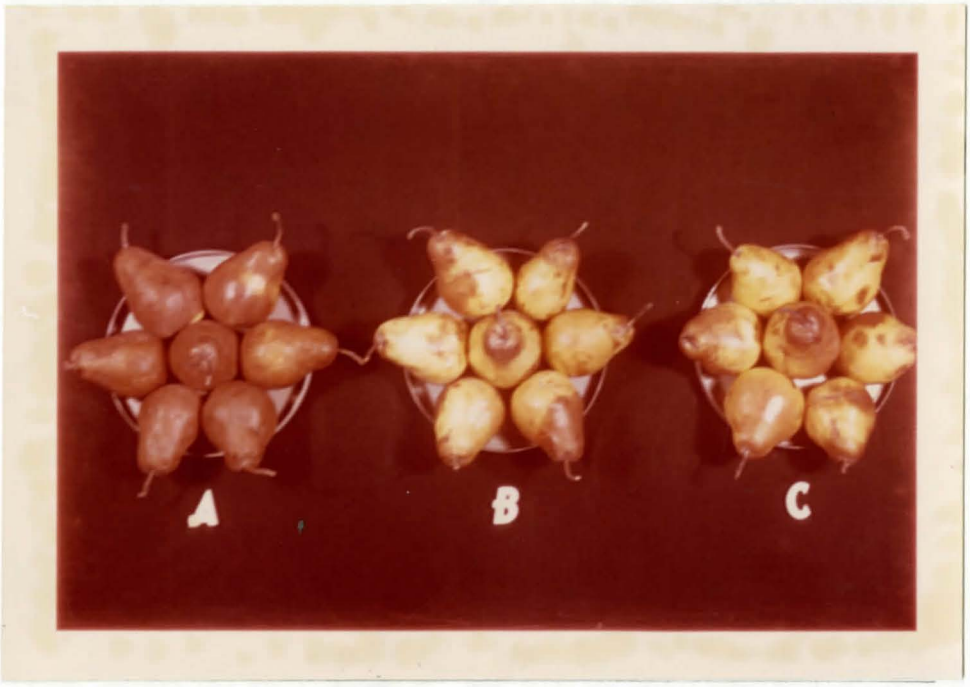

Figure 50. Effects of chemical treatments on physical quality of pears (var. Bartlett) stored at 40° F and 85 percent relative humidity (photographed 45 days after treatments). Left to right: A = control; B = Captan, 1200 ppm; C = Mycostatin, 100 ppm (1960).

Table 7. Effects of chemical treatments and Duratite packaging film on percentage of marketable fruits and fungus growth on pears (var. Bartlett); the pears inoculated with fungi (penicillium, Rhizopus, Alternaria, and Monilinia species) prior to chemical treatments and packaging and then stored at 40° F and 85 percent relative humidity for 60 days (observations taken at 30, 45, and 60 days intervals, 1960)

Days in storage	Chemical	Concentration ppm	No. of fruits	Percent marketable fruits	Fungi observed
30	Control		45	66.66	Penicillium
	Captan	1200	45	93.33	Penicillium
		2400	45	95.55	Penicillium
	Mycostatin	100	45	95.55	Penicillium
		200	45	95.55	Penicillium
	Dowicide-A	1000	45	97.77	Penicillium
		2000	45	97.77	Penicillium
	Sorbic acid	5000	45	93.33	Penicillium
		10000	45	93.33	Penicillium
45	Control		45	20.00	Penicillium
	Captan	1200	45	82.22	Penicillium
		2400	45	93.33	Penicillium
	Mycostatin	100	45	93.33	Penicillium
		200	45	93.33	Penicillium
	Dowicide-A	1000	45	86.66	Penicillium
		2000	45	82.22	Penicillium
	Sorbic acid	5000	45	82.22	Penicillium
		10000	45	84.44	Penicillium
60	Control		45	0.00	Penicillium, Rhizopus Alterneria
	Captan	1200	45	40.00	Penicillium
		2400	45	57.77	Penicillium
	Mycostatin	100	45	57.77	Penicillium
		200	45	31.11	Penicillium
	Dowicide-A	1000	45	40.00	Penicillium
		2000	45	46.00	Penicillium
	Sorbic acid	5000	45	24.44	Penicillium, Rhizopus
		10000	45	44.44	Penicillium

Figure 51. Effects of chemical treatments and Duratite film on physical quality and fungal growth on pears (var. Bartlett) stored at 40° F and 85 percent relative humidity (photographed 70 days after storage). Top row = lower chemical concentrations; bottom row = higher chemical concentrations. Left to right: A = Captan, 1200 ppm and 2400 ppm; B = Dowicide-A, 1000 ppm and 2000 ppm; C = Mycostatin, 100 ppm and 200 ppm; D = sorbic acid, 5000 ppm and 10,000 ppm (1960).

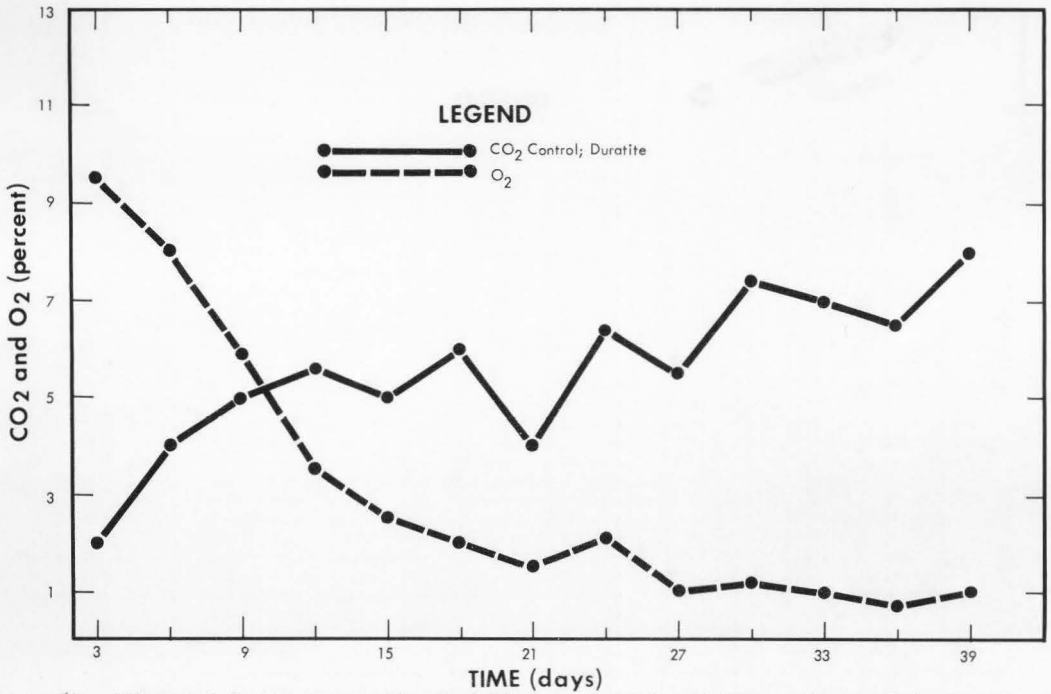

Figure 52. Effects of Captan, Mycostatin, Dowicide-A, and sorbic acid on respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. (The curves present in this figure serve as nontreated controls to be used for the comparison with curves presented in figures 50 and 51, 1961).

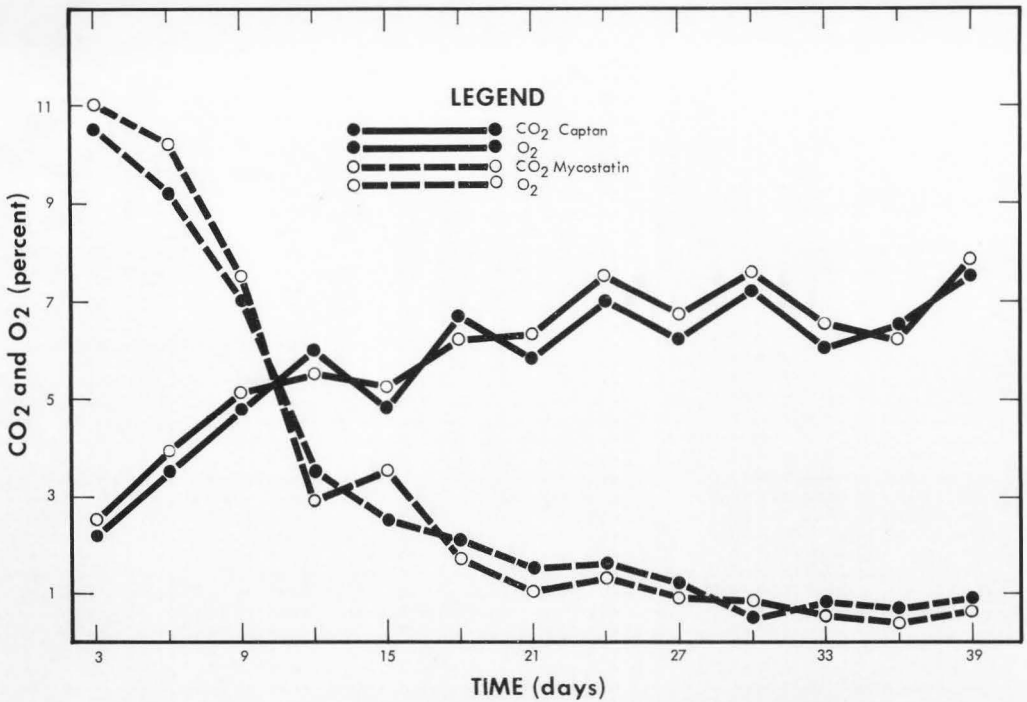

Figure 53. Effects of Captan and Mycostatin (2400 ppm and 200 ppm) on respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 3 days after the storage (1961).

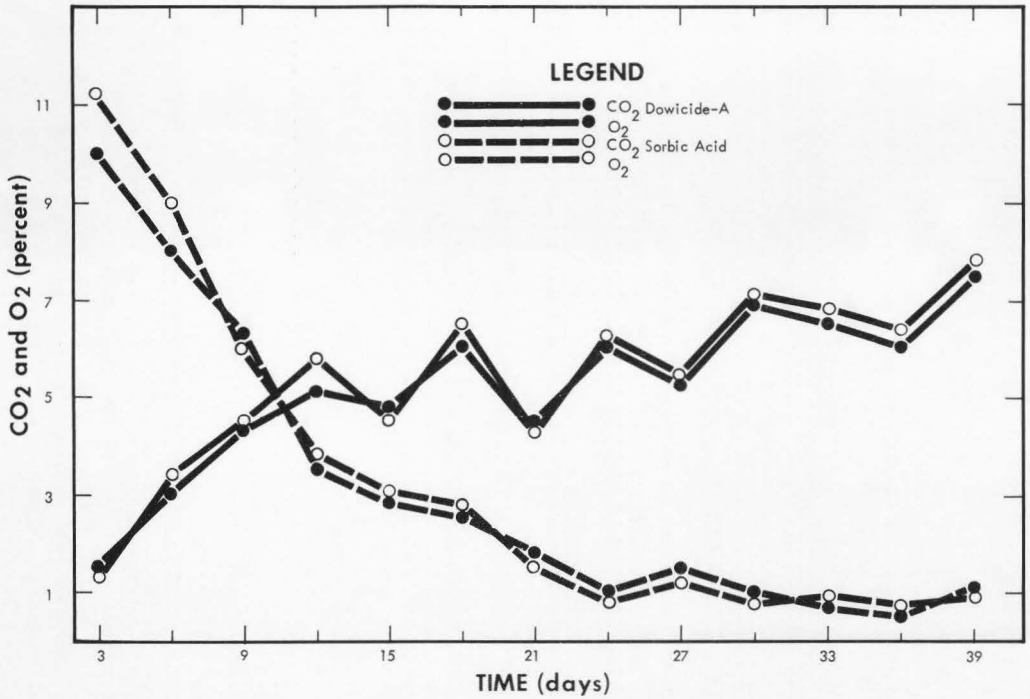

Figure 54. Effects of Dowicide-A and sorbic acid (2000 ppm and 10,000 ppm) on respiratory behavior of pears (var. Bartlett) packaged in Duratite film and stored at 40° F and 85 percent relative humidity for 39 days. Observations started 3 days after the storage (1961).

CO_2 during the first 15 days and a significant decrease in level of O_2 during the first 25 days of storage. After these elapsed times of storage the level of O_2 remained fairly constant but CO_2 continued to rise. The chemical treatments of Captan and Mycostatin maintained significantly lower levels of CO_2 and higher levels of O_2 than sorbic acid. Similar statistical results can be seen in appendix tables 18b and 18c for 1961 data.

Experiment IV: Effects of Ionizing Radiation on Respiratory Behavior of Peaches

Effects of beta radiation on peaches (var. Elberta)

The results obtained with the radiation doses applied to peaches are presented graphically in Figure 55. The climacteric peak was shown by the controls after only 4 days. Although the respiration rate of the controls was low, the climacteric was reached quite soon. The radiation dosages 1×10^5, 3×10^5, and 5×10^5 rads delayed the climacteric rise by 4, 18, and 14 days, respectively. All the radiation dosages delayed the senescence of peaches. In general, the increase in CO_2 evolution was in direct proportion to the radiation dose applied. The accelerated respiratory rate of irradiated fruits (Figure 55) may be caused by the depolymerization of starch or carbohydrates to simpler more readily used forms by the ionizing radiation (Burns, 1959; and Desrosier, 1959).

The unusual rise in climacteric peak in the 1×10^5 rad treatment may be due to a stimulatory effect of the low dosage radiation on the enzymic system responsible for respiration (Desrosier, 1959).

Effects of gamma radiation on peaches (var. Gem)

The respiratory activities of the fruits exposed to 1×10^5, 3×10^5,

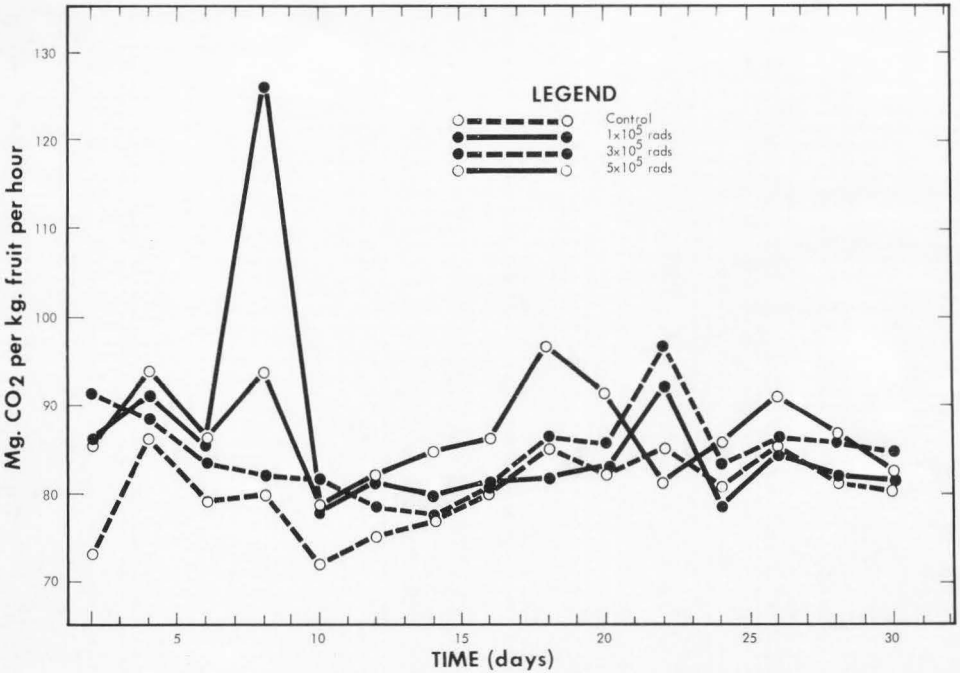

Figure 55. Effects of beta radiation doses (0 x 10^5, 1 x 10^5, 3 x 10^5, and 5 x 10^5 rads) on respiratory behavior of peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 30 days after transportation for one day at ambient temperature subsequent to irradiation. Observations started one day after storage (1960).

and 5×10^5 rads including nonirradiated controls are summarized graphically in Figure 56. It can be noted that gamma radiation behaved in exactly the same manner as beta radiation in accelerating the respiratory system. The CO_2 evolution was directly proportional to the dose applied (Burns, 1959; and Desrosier, 1959). The climacteric peak occurred in the controls after 4 days of storage. The radiation dosages 1×10^5, 3×10^5, and 5×10^5 rads delayed the climacteric rise beyond the controls by 2, 10, and 0 days, respectively. A 10-day delay of the climacteric appears to be very significant. This radiation treatment may prove to be important in prolonging fruit storage life.

The statistical analysis presented in appendix table 12a shows that the amount of CO_2 given off by the irradiated fruits as measured on alternate days increases significantly with the elapse of storage time. The gamma radiation dosage of 1×10^5 rads significantly inhibits the respiration. All dosages of beta radiation behave similarly, although an increase in CO_2 evolution was proportional to the dose applied.

Experiment V: Effects of Ionizing Radiation on Fungus Growth

Penicillium, Rhizopus, and Alternaria species were irradiated with beta rays at dosages of 1×10^5, 3×10^5, and 5×10^5 rads 3 days after their establishment on agar media in petri dishes. The results obtained from the irradiation treatments are shown in Figure 57 and table 8. It is clear from this figure and table that the inhibition effect of radiation is directly proportional to the dose applied (Fields, 1959; and Beraha et al., 1960). Therefore, radiation doses within these limits may be of importance in preventing fungus growth and increasing the shelf life of fresh fruits and other products.

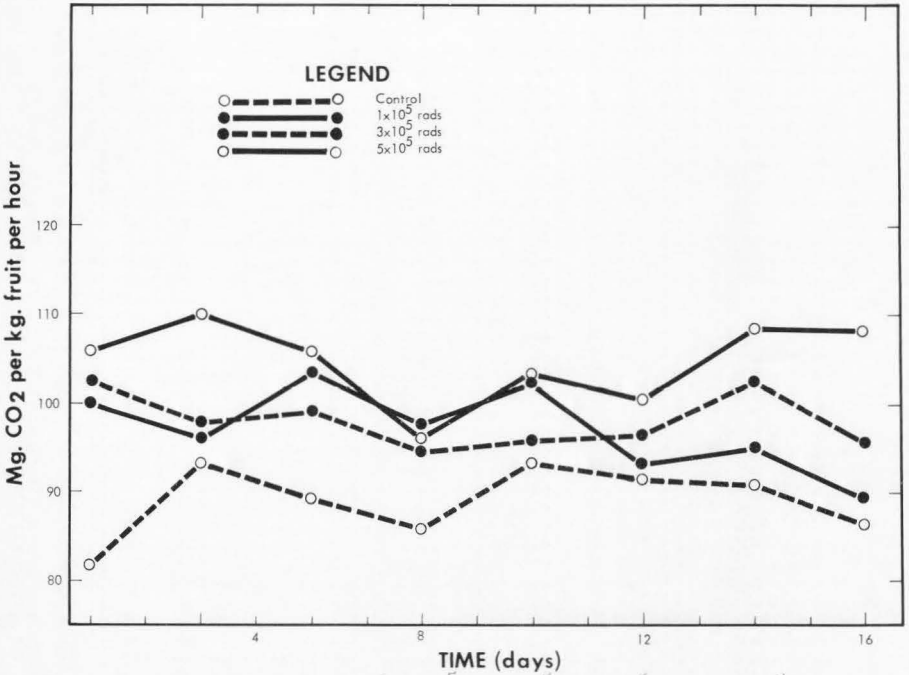

Figure 56. Effects of gamma radiation doses (0 x 10^5, 1 x 10^5, 3 x 10^5, and 5 x 10^5 rads) on the respiratory behavior of peaches (var. Gem) stored at 40° F and 85 percent relative humidity for 16 days after transportation for one day at ambient temperature subsequent to irradiation. Observations started one day after the storage (1960).

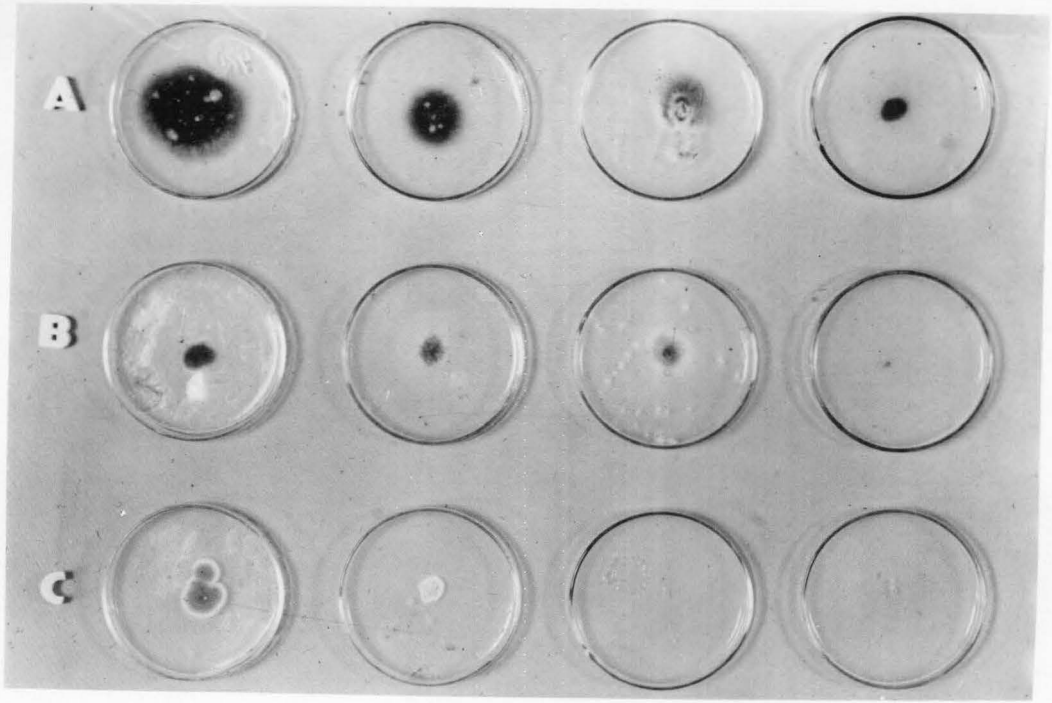

Figure 57. Effects of beta radiation on growth of: A = Alternaria, B = Rhizopus, and C = Penicillium species (photographed 5 days after irradiation). Left to right for A, B, and C = control, 1×10^5, 3×10^5, 5×10^5 rads (1960).

Table 8. Effects of beta radiation on fungus growth *in vitro* (irradiated 3 days after transfer and data collected 5 days after irradiation, 1960)

Fungi	Radiation dose (rads)	Effectiveness[a] of the treatment
Alternaria	Control	+ + + +
	1×10^5	+ + +
	3×10^5	+ +
	5×10^5	+
Rhizopus	Control	+ + + +
	1×10^5	+ + +
	3×10^5	+ +
	5×10^5	+
Penicillium	Control	+ + + +
	1×10^5	+ + +
	3×10^5	+ +
	5×10^5	+

[a] + = no growth. ++ = slight growth. +++ = moderate growth. ++++ = normal growth.

Experiment VI: Effects of Packaging Films and Ionizing Radiations on Respiratory Behavior, Fungus Growth, and Marketable Quality of Peaches

Effects of beta radiation and Duratite film on peaches (var. Elberta)

The experimental results are presented in Figure 58. The levels of CO_2 and O_2 at the first observation in all dosages were about 3.0 to 3.5 percent and 9.5 to 10.5, respectively. A consistent rise in CO_2 during the first 10 days occurred. This continued for the next 22 days with gradually increasing levels. The last observational points on all the curves show a marked rise in the CO_2 level. This rise can probably be explained on the basis of microbial contribution to CO_2 evolution. Micro-organisms may have started growing sometime earlier underneath the skin of the fruits. This could not be detected with the naked eye. It can be concluded from the above mentioned curves that the CO_2 accumulation inside the bags increased with the increasing irradiation dose (Burns, 1959). This increase of CO_2 evolution appeared to be related to the activation of the substrate available to respiratory enzymes. It was observed that radiation doses of 1×10^5 and 3×10^5 rads proved to be effective in controlling fungus growth and in keeping fruits for longer periods of time than in the control and the 5×10^5 dosage (table 9 and Figure 59). The statistical analysis is shown in appendix table 19 and indicates that radiation treatments are significantly superior to control after 40 days of storage. The dosages 1×10^5 and 3×10^5 rads did not show statistically significant differences from the dosage 5×10^5 rads. It was noted that fruit irradiated with 5×10^5 rads were infested by fungi earlier than that subject to the other dosages. It

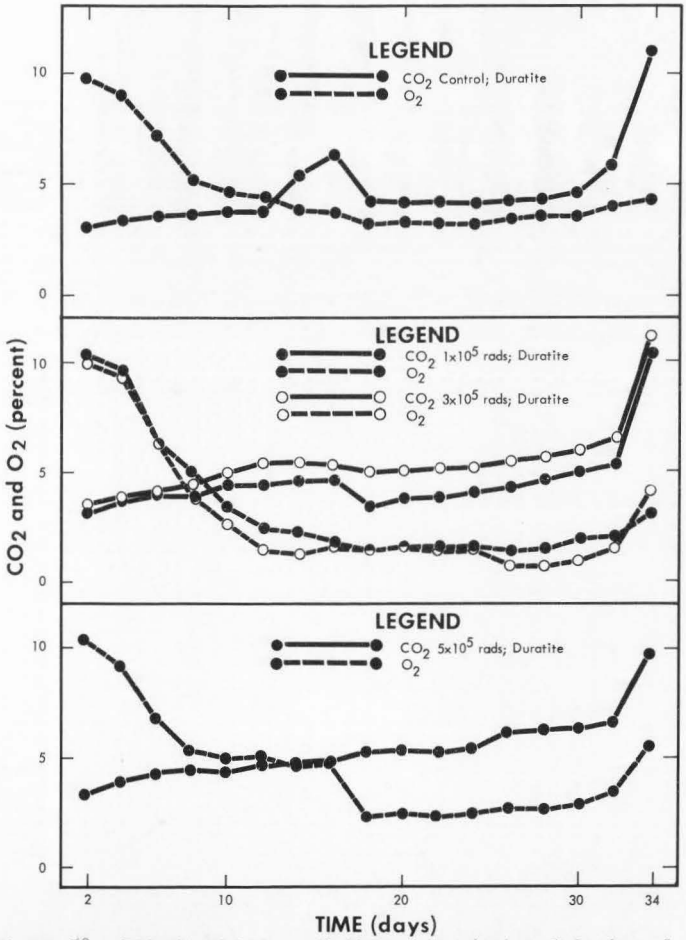

Figure 58. Effects of beta radiation on respiratory behavior of peaches (var. Elberta) packaged before irradiation in Duratite film and then stored at 40° F and 85 percent relative humidity for 34 days after transportation for one day at ambient temperature subsequent to irradiation. Observations started one day after the storage. Top to bottom: control, 1 x 10^5 rads, 3 x 10^5 rads, and 5 x 10^5 rads (1960).

Table 9. Effects of beta radiation and Duratite packaging film on percentage of marketable fruits and fungus growth on peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 50 days (observations taken at 30, 40, and 50 days intervals, 1960)

Days in storage	Radiation dose (rads)	No. of fruits	Percent marketable fruits	Fungi observed
30	Control	30	100.00	none
	1×10^5	30	100.00	none
	3×10^5	30	93.33	Penicillium, Alternaria
	5×10^5	30	90.00	Penicillium, Alternaria
40	Control	30	60.00	Penicillium, Rhizopus, Alternaria
	1×10^5	30	93.33	Penicillium, Alternaria
	3×10^5	30	66.66	Penicillium, Alternaria
	5×10^5	30	33.33	Penicillium, Alternaria
50	Control	30	10.00	Penicillium, Rhizopus
	1×10^5	30	70.00	Penicillium, Alternaria
	3×10^5	30	13.00	Penicillium, Alternaria
	5×10^5	30	3.33	Penicillium, Alternaria

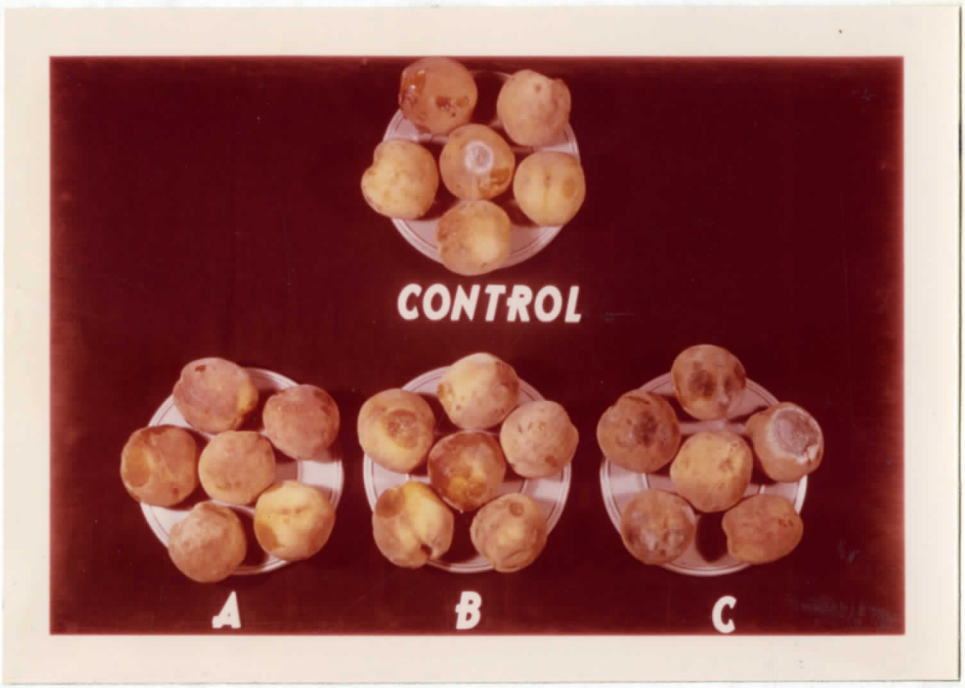

Figure 59. Effects of beta radiation and Duratite film on the physical quality and fungus growth on peaches (var. Elberta) stored at 40° F and 85 percent relative humidity (photographed 40 days after irradiation). Left to right: A = 1 x 10^5, B = 3 x 10^5, C = 5 x 10^5 rads (1960).

was assumed that the spoilage of fruit irradiated with higher dosage was caused by excess radiation injury to the tissues of the fruit. Radiation injured tissue becomes more susceptible to fungus attack. Perhaps the tissue loses inherent defense mechanisms.

The analysis of variance presented in appendix tables 20 and 20a shows the amount of CO_2 given off and O_2 consumed by the irradiated fruits as measured on alternate days of storage. The data indicate that the CO_2 levels inside the films increase significantly while the O_2 levels decrease during the first 10 days of storage. Beyond this time the levels of these gases remained fairly constant. The increase in CO_2 accumulation is significantly proportional to the dose applied.

Effects of gamma radiation and Duratite and polyethylene films on peaches (var. Gem)

The results of the respiratory activity of the peaches (var. Gem) exposed to 1×10^5, 3×10^5, and 5×10^5 rads respectively are summarized in Figures 60 and 61, along with similar observations on normally maturing unirradiated fruit. These observations were taken under modified atmospheric conditions (closed in Duratite and polyethylene bags). The curves resulting from the irradiation treatments were similar for both films except that the levels of CO_2 maintained in polyethylene bags were lower than in Duratite bags. This difference is attributed to permeability differences of the plastic materials in the bags.

The curves presented in Figure 60 show the levels of atmospheric gases attained in Duratite bags; the level of CO_2, regardless of the dose, rose as high as 10 to 16 percent. The percent CO_2 maintained in the higher dosage is lower than that of the control and the other two

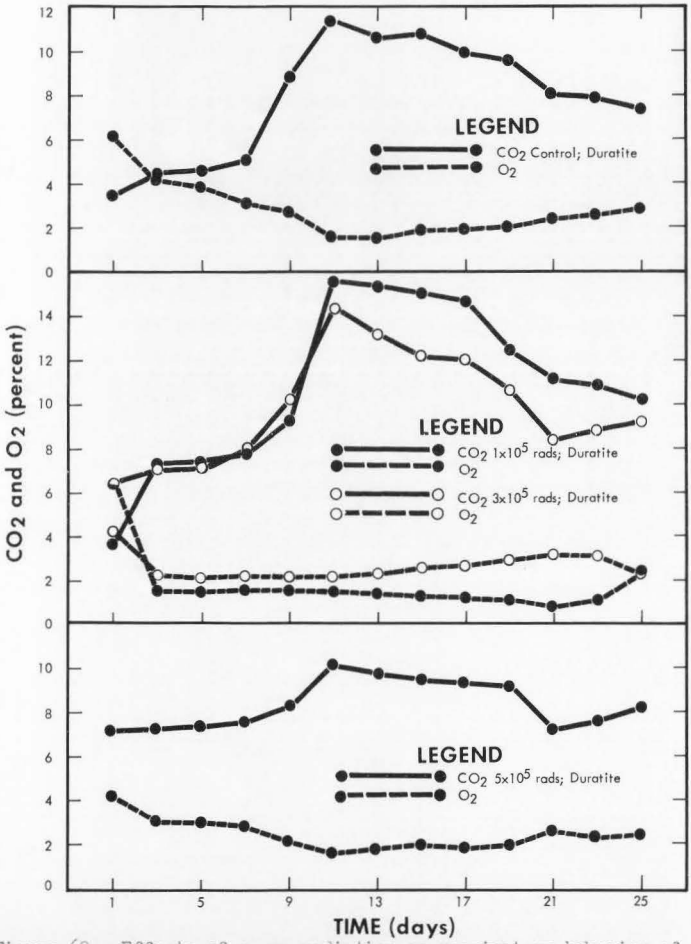

Figure 60. Effects of gamma radiation on respiratory behavior of peaches (var. Gem) packaged before irradiation in Duratite film and then stored at 40° F and 85 percent relative humidity for 25 days, after transportation for one day at ambient temperature subsequent to irradiation. Observations started one day after the storage. Top to bottom: control, 1 x 10^5 rads, 3 x 10^5 rads, and 5 x 10^5 rads (1960).

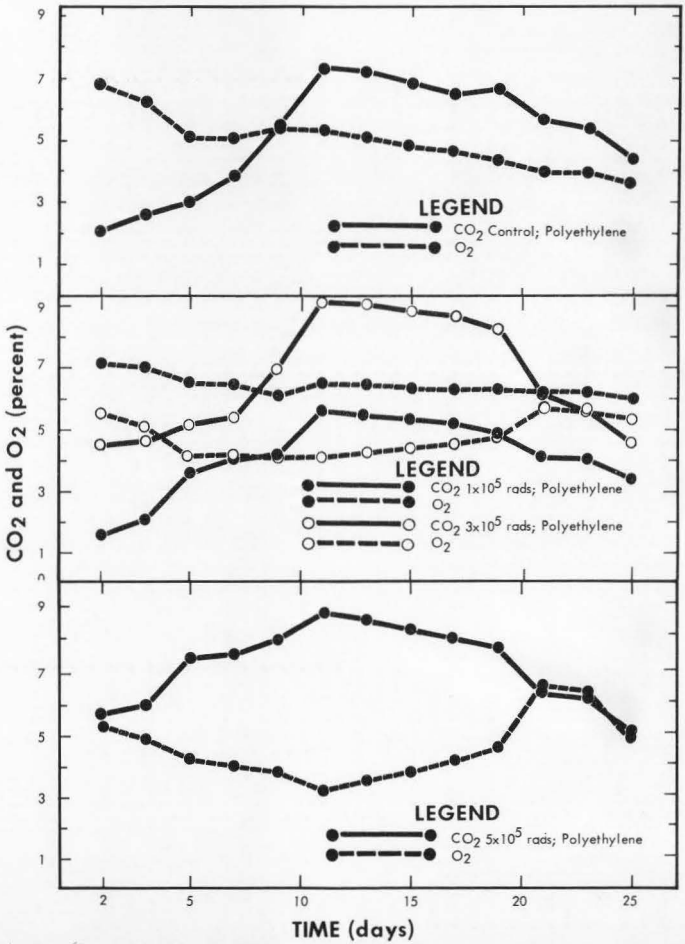

Figure 61. Effects of gamma radiation on respiratory behavior of peaches (var. Gem) packaged before irradiation in polyethylene film and then stored at 40° F and 85 percent relative humidity for 25 days after transportation for one day at ambient temperature subsequent to irradiation. Observations started one day after the storage. Top to bottom: control, 1 x 10^5 rads, 3 x 10^5 rads, and 5 x 10^5 rads (1960).

dosages. It seems that as the dose level increased, the CO_2 maintained in the bag decreased. An explanation for this might be that respiratory enzymic systems were inactivated by the higher radiation dosages. At 5×10^5 rads radiation dose, injuries appearing as black areas on the surface of the peaches were noted. These surface injuries indicate that excessive radiation injury occurred. It is quite likely that enzymic systems must have been upset (Desrosier, 1959).

Figure 61 shows results obtained with polyethylene bags. Perhaps because the polyethylene bags were more permeable to CO_2, lower levels of CO_2 were maintained in these experiments (Figures 62 and 63). The levels of CO_2 concentration were higher in the 3×10^5 and 5×10^5 rads dosages than in the control and in 1×10^5 rads dosage. It seems that the same radiation doses behave differently in different bags. At the dosage level of 1×10^5 rads, the CO_2 curve remained lower than the O_2 curve. This result may have been caused by some leakage in the bags or might be a real effect of the irradiation dosage and bag combination. If these curves are the real effect of treatments, then this combination of treatments might prove successful in keeping the fruits for longer periods of time by maintaining this CO_2 and O_2 ratio inside the polyethylene bags.

The first readings taken with both types of packaging films in all gamma treatments show lower levels of O_2 and slightly higher levels of CO_2 than in comparable beta radiation treatments. This suggests that gamma radiation induces higher respiration rates than beta radiation during the first part of the storage period.

The marketable quality of the gamma-radiated fruit was similar to that obtained with beta radiation with the exception that the gamma

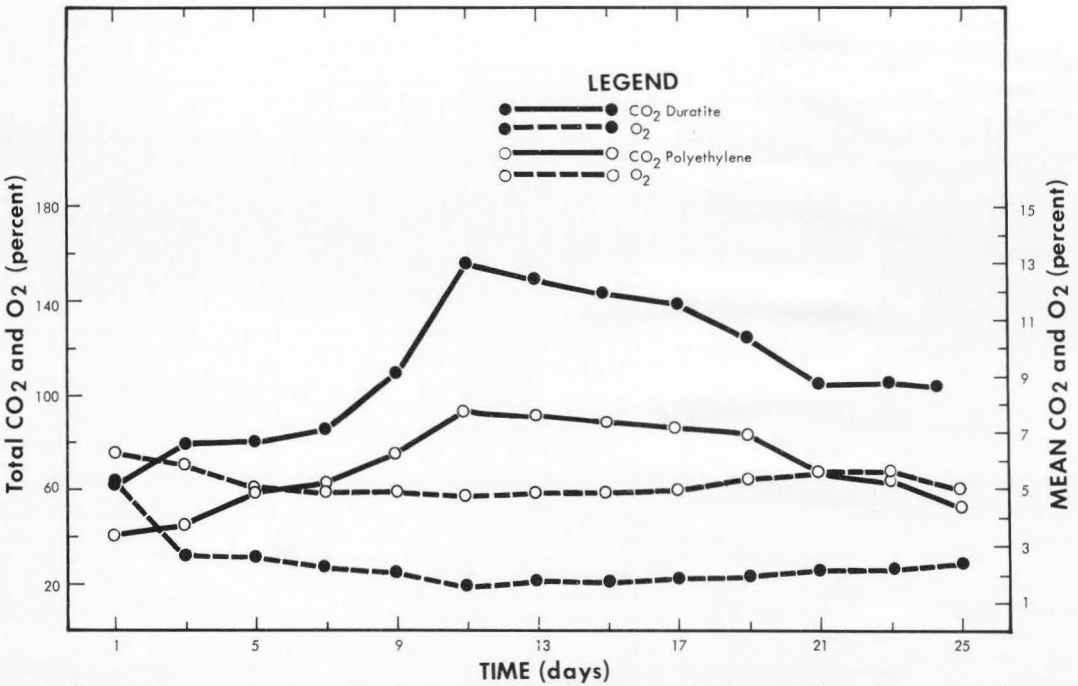

Figure 62. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of the radiation doses) in atmospheres surrounding peaches (var. Gem) stored at 40°F and 85 percent relative humidity for 25 days. Total CO_2 and O_2 percent represents the total of three bags of each kind under all treatments at alternate days. Mean CO_2 and O_2 percent represents the average of all the bags in all the treatments at alternate days (1960).

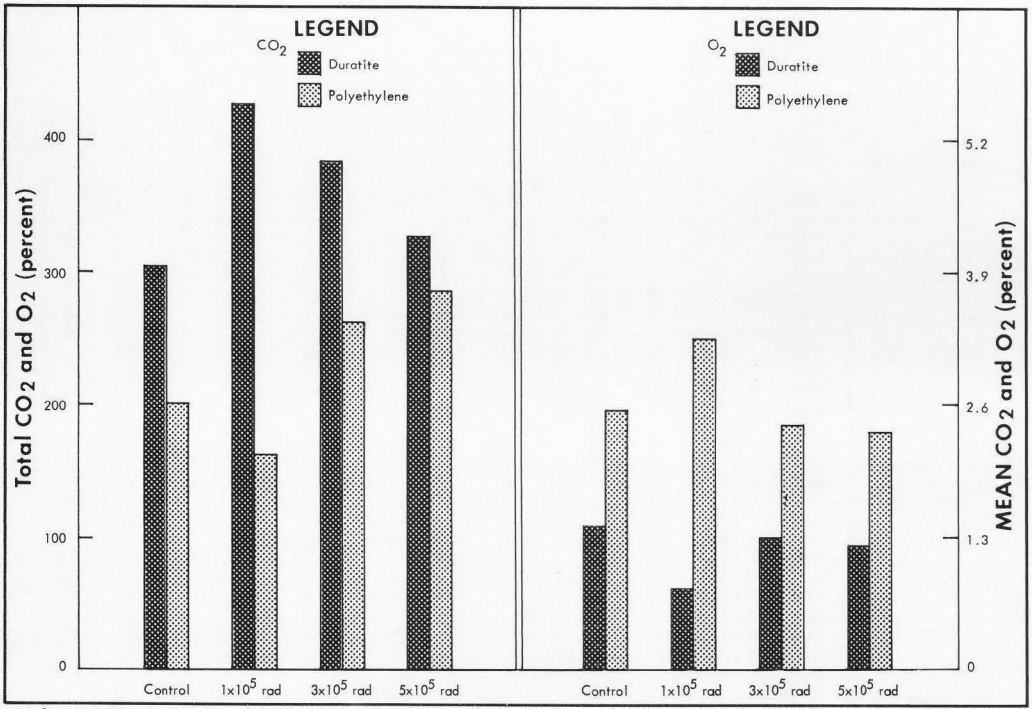

Figure 63. Effects of Duratite and polyethylene films on the maintenance of CO_2 and O_2 levels (regardless of storage days) in atmospheres surrounding peaches (var. Gem) stored at 40° F and 85 percent relative humidity for 25 days. Total CO_2 and O_2 percent represents the total of all the observational days and three bags in each day. Mean CO_2 and O_2 represents the average of all the bags in all observational days under each treatment (1960).

radiation dose (3×10^5) was best in controlling spoilage by fungi while the beta radiation dose (1×10^5) was the best for fungus control (table 10 and Figure 64). In general, fruits packaged in polyethylene bags seemed to be preserved better than fruits packaged in Duratite bags.

The statistical comparison of gamma radiation dosages for marketable quality of fruit is presented in appendix table 21. The conclusions can be drawn that ionizing radiation dosages within certain limits are generally effective in preventing fresh fruits from spoilage by fungi (McArdle et al., 1957; Beraha et al., 1955, 1959; Burns, 1959; and Hannan, 1954).

The statistical analyses presented in appendix tables 22 and 22a show the amount of CO_2 given off and O_2 consumed by the fruits as measured on alternate days of storage. The data indicate that during the first 7 days of storage the increase in level of CO_2 is not significant while the decrease in level of O_2 is significant. On the seventh and eighth days the rise in CO_2 level was significant while the O_2 level remained fairly constant. The radiation dosage 5×10^5 rads maintained a significantly lower level of CO_2 than the other dosages (1×10^5 and 3×10^5 rads). Polyethylene film (regardless of the radiation dosages) maintained significantly lower levels of CO_2 and higher levels of O_2 than Duratite film.

Table 10. Effects of gamma radiation and packaging films on percentages of marketable fruits and fungus growth on peaches (var. Gem) stored at 40° F and 85 percent relative humidity for 40 days (observations taken at 20, 30, and 40 days intervals, 1960)

Days in storage	Radiation dose (rads)	Packaging film: Duratite — No. of fruits	Duratite — Percent marketable fruits	Duratite — Fungi observed	Polyethylene — No. of fruits	Polyethylene — Percent marketable fruits	Polyethylene — Fungi observed
20	Control	18	100.00	none	30	100.00	none
	1×10^5	18	100.00	none	30	100.00	none
	3×10^5	18	100.00	none	30	100.00	none
	5×10^5	18	72.22	Penicillium Alternaria	30	90.00	Penicillium Alternaria
30	Control	18	72.22	Penicillium Rhizopus	30	66.66	none
	1×10^5	18	72.22	Penicillium	30	83.33	none
	3×10^5	18	94.44	Penicillium Alternaria	30	96.66	Penicillium Alternaria
	5×10^5	18	55.55	Penicillium Alternaria	30	66.66	Penicillium Alternaria
40	Control	18	38.89	Penicillium Rhizopus	30	30.00	Penicillium Alternaria Rhizopus
	1×10^5	18	55.55	Penicillium	30	50.00	Penicillium
	3×10^5	18	66.66	Penicillium Alternaria	30	80.00	Penicillium Alternaria
	5×10^5	18	16.66	Penicillium Alternaria	30	23.33	Penicillium Alternaria

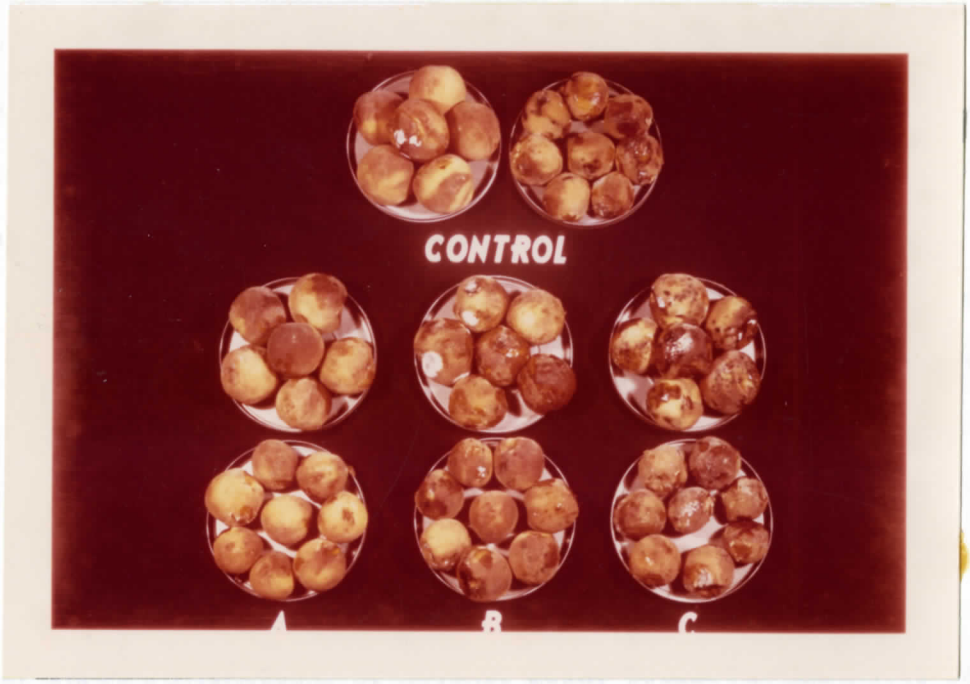

Figure 64. Effects of gamma radiation and packaging films on the physical quality and fungus growth on peaches (var. Gem) stored at 40° F and 85 percent relative humidity (photographed 40 days after irradiation). Top row = Duratite; bottom row = polyethylene. Left to right: control = polyethylene and Duratite, A = 1 x 10^5 rads, B = 3 x 10^5 rads, C = 5 x 10^5 rads (1960).

GENERAL DISCUSSION

Effects of Chemicals on Respiration

Post-harvest application of certain chemicals such as Na-malonate (0.001 M), 3-indolepropionic acid (0.0005 M), hippuric acid (0.0005 M), and benzimidazole (0.001 M and 0.0005 M) retarded the rate of respiration of preclimacteric apple fruits (Woodruff and Crandall, 1958). The respiratory rate of tomato stem slices was reduced to about 45 percent of the control by 0.001 M indoleacetic acid (Eberts, Burries, and Riker, 1951). Likewise, Mitchell, Burries, and Riker (1949) reported the effects of several plant-growth substances on the respiration of various plant tissues. They further stated that the effective range of plant growth substances tested was between 0.005 M and 0.00005 M. Smock, Edgerton, and Hoffman (1952), working on apples, reported that in general the respiratory rate of this fruit was inhibited with the pre-harvest spray applications of malonic acid, potassium malonate, and iodoacetic acid. They also reported that the pre-harvest application of maleic hydrazide sometimes retarded the respiratory rate of apples after harvest.

The extent of respiration determines the rate by which the carbohydrates are used in the process of respiration of any fruit. The utilization of carbohydrates, the stored food materials of the living fruit, may be controlled by inhibiting the activity of the enzymic systems responsible for respiratory reactions. This process may be achieved by the application of certain chemical treatments which have inhibitory effects on the respiratory system of the fruit. Therefore,

it seems possible that by retarding the rate of respiration with the application of certain chemicals, fruits may be stored longer subsequent to harvest.

Effects of Chemicals on Microbial Growth

Ayre and Denisen (1958) suggested that strawberries and black and red berries dipped in solutions containing Myprozine had lower microbial counts after storage than did the controls; the trials with other antifungals showed that Candidin, Ascosin, and Nystatin were stimulatory to mold and yeast development. Likewise, Muller (1958) reported that Streptomycin and Neomycin had no influence on fungi; Eulicin, Candicidin, Mycostatin, Filipin, Amphotericin-B, and Candicidin were effective against many fungi but not against bacteria. DiMarco (1959) reported that out of 15 chemicals at several concentrations tested, six showed promise of controlling post-harvest decays of strawberries and peaches. The most effective chemicals were Captan, Dithane, Dowicide-A, Mycostatin, and sorbic acid. Likewise, Almandil (1960) reported that Captan and Mycostatin were most effective inhibitors for Penicillium, Aspergillus, and yeast, in vitro.

Fungi can be killed by various agencies, such as heat, ultraviolet light, and chemicals. Some chemicals make a fungus appear dead, when it no longer grows or reproduces. When the chemical is washed out of the fungus with water, the fungus will grow again. In this case the chemical is said to be fungistatic because it keeps the fungus static. There are other chemicals which permit a fungus to grow but which prohibit it from reproducing by sporulation. These chemicals are called antisporulants. The chemicals which actually kill the fungus are called fungicides. The control of fungi by fungicides comprises two basic

principles, protection and therapy. To deal with the fungus before it attacks the host is protection and to deal with the fungus after it has entered the host is therapy. Many characteristics of fungi are altered by chemical treatments. The following characteristics are known to be affected: growth, morphology, sporulation, spore germination, swelling of spores, mitosis, permeability, and respiration.

It is thought that a fungicide penetrates the fungus cells and hence poisons the growing nucleus of the fungus. Usually fungi find their food supply outside their own cells. For example, the fungus, Myrothecium verrucaria, lives on the cellulose of cotton fibers and it hydrolyzes the cellulose to glucose which the fungus can use, by excreting cellulolytic enzymes. Therefore, it is easy to postulate a substance that could inhibit the activity of the cellulase and thus starve the fungus to death. The compound need not penetrate the cell (Finholt et al., 1952). Several compounds appear to act neither outside nor inside the membrane but on the membrane of the fungus and destroy the ability of the cell to take in or reject food substances.

Effects of Modified Atmosphere on Respiration and Fungus Growth

The respiratory rate of a given fruit is not constant as it ripens. It varies even if temperature and other conditions are held constant. It has been noted that the rate of respiration declines prior to the time of harvest. Following this low point on the respiratory curve there is a rise in the respiration rate. The rate continues to increase until it reaches a maximum which is then followed by a gradual decline. This rise in respiratory rate is called the "climacteric" rise and the hightest point in the curve is called the "climacteric peak" (Kidd and West, 1930, 1945). When fruits are declining in rate following the

peak, they are said to be in "senescence" (Kidd and West, 1936).

It is important to know the respiratory curve for each fruit, so that one can harvest the produce before or after the climacteric peak, depending upon the kind of fruit, variety, and purpose for which the fruits are to be used. For most purposes, fruits would seldom, if ever, be harvested in a "post-climacteric" condition. The magnitude of the respiratory rise in fruits depends upon a number of factors. Kind of fruit, variety, climatic conditions during the growing season, temperature of storage, and nature of the surrounding atmosphere in storage are some of the conditions that may cause the climacteric peak to be higher in one case than in another.

The significance of the climacteric rise has been fully appreciated. The climacteric rise in respiration is the critical state which separates the stages of development and maturation from the stage of functional breakdown. The climacteric denotes the beginning of the end. Any treatment or condition which delays the onset of the climacteric delays also senescence (Biale, 1950).

The presence of CO_2 around fresh horticultural crops tends to slow down the respiratory rate. In general, the higher the concentration of CO_2 the more the respiratory rate is depressed (Kidd and West, 1927; Van Doren, 1939). The effect of CO_2 might be explained on the basis of the law of mass action; that is, with accumulation of CO_2 around the fruit, the rate of respiration would be slowed down because one of the end products was not being removed (Smock and Van Doren, 1941). How CO_2 slows down the respiratory rate of fruits is perhaps not yet known. However, it has been suggested by Thornton (1933) that in some plant tissues there is an effect of CO_2 on pH of tissues and hence on

respiration. This might further raise the question as to whether the change in pH accompanies the retarded respiration or causes it. The CO_2 effect on respiration has been used commercially in controlled atmosphere storage, where CO_2 evolved by the fruits in respiration is utilized as a source of CO_2 to retard ripening rate.

As the presence of CO_2 influences the rate of respiration of the fruit, the amount of O_2 present in the atmosphere equally affects the rate of respiration of the fresh products involved. This can be explained by the fact that O_2 is one of the reacting materials in the process of respiration. When it is reduced either in the external or internal atmospheres of the fruit, the respiratory rate is reduced. In this connection, Van Doren (1939) explains that reduction in O_2 concentration has a more marked effect on respiration of apples than CO_2 accumulations. The inhibiting effect of low O_2 concentration on respiration of fruits and vegetables is used in controlled atmosphere storage. Here, also, in the storage the O_2 is lowered by means of fruit respiration itself (Kidd and West, 1935).

There are limits to the amounts of CO_2 and O_2 that may be used in trying to retard the respiratory rate. Some fruits are very sensitive to excess quantities of CO_2 and cannot tolerate more than 1 to 2 percent at a given temperature, whereas others can do well at even 8 to 10 percent at the same temperature. Therefore, it is important to keep in mind that every kind of fruit and even the varieties of the same kind of fruit differ in their requirements for the CO_2 and O_2 ratio in order to retard the respiratory rate effectively without affecting the quality of the fruit. Hence, it is the duty of the physiologist to determine the respiratory behavior of all kinds of fruits under a given condition

and to suggest to the growers and storage operators the CO_2 and O_2 requirements of each fruit, so that they may store their products for longer periods of time by retarding respiration and ripening rate without excessive loss.

Fungi, like other living organisms, require a suitable atmosphere for their normal growth. If the atmosphere around fungi is modified by increasing the percent of CO_2 and lowering the percent of O_2 from their normal percentages in the atmosphere, the fungi will usually not grow as profusely as they would in the normal atmosphere. As the CO_2 level in the atmosphere surrounding fungi is increased to a maximum and O_2 level to a minimum, the fungi will die instead of growing normally because of the CO_2 accumulation and lack of O_2 (Smock and Van Doren, 1941).

Effects of Ionizing Radiations on Biological Materials

A result of the absorption of beta rays or gamma rays by biological tissue is the ionization and excitation of the atoms in which rays are absorbed. The process of ionization involves the production of a positive ion by the ejection of an electron and the production of a negative ion by the attachment of this electron to another atom. When an atom is ionized the molecule of which it is a part undergoes a chemical change.

Gamma rays interact with matter by three processes as follows: (1) photo-electric effect, (2) Compton scattering, and (3) pair production. The photoelectric takes place when a gamma ray with less than 0.1 Mev energy knocks out an orbital electron. This electron then acts as a free electron with very high energy.

In 1922, Compton stated that when gamma rays fall on carbon, or other material of low atomic weight, the scattered radiation contains some rays of longer wave length than the incident gamma rays. This scattering is produced by the electrons present in the carbon atoms. Therefore, it appears that interaction between gamma rays and electrons results in an increase in the wave length of the former. Thus the energy is taken up from the incident gamma rays in ejecting an electron and the scattered radiation is reradiated as a photon of lower energy with a longer wave length. This ejected electron again acts as a free electron of high energy.

When a gamma ray has energy greater than 1.05 Mev, pair production may occur. This means that a gamma ray is destroyed as it strikes an atom to produce an electron and positron pair. This process occurs extremely close to the nucleus of an atom. The reaction is the conversion of energy into matter, following the Einstein equation $E = mc^2$. An electron has a mass of 9.107×10^{-28} grams. The speed of light expressed by "C" is 3×10^{10} cm per second and E = 0.51 Mev per particle. Therefore, it is expected that similar results can be obtained by direct irradiation with beta rays or gamma rays.

Biologists are of the opinion that the target theory of radiation is principally responsible for irradiation effects. This theory proposes that if a fast-moving charged particle hits a biological material, the biological function of this material is altered or destroyed. During the past years several scientists have postulated that the direct hits may be responsible for some specific biological effects. On the other hand, many effects are no doubt caused by the ionization induced by the radiation.

Most biological material, such as fruit, contains water. When water-containing material is irradiated, the ionization of a portion of the water results in the formation of highly reactive hydrogen and hydroxyl radicals, $H_2O^+ \longrightarrow H^+ + OH^-$. These radicals are chemically very reactive and may act as reducing and oxidizing agents as well as agents which cleave carbon to carbon bonds. In the presence of dissolved oxygen the hydrogen atom may combine with molecular oxygen to form the very reactive O_2H peroxide radical, which can form hydrogen peroxide as follows:

$$H^+ + O_2 \longrightarrow O_2H$$

$$2O_2H \longrightarrow H_2O_2 + O_2$$

In the same way as above the hydroxyl radicals may also form hydrogen peroxide:

$$OH^- + OH^- \longrightarrow H_2O_2$$

Therefore, radiobiologists agree that the theory of indirect action offers a wider basis for biochemical changes in biological material than the theory of direct action (Fields, 1959).

The death rate of the micro-organisms is directly proportional to the radiation dose applied. The higher the dose the more fatal is the effect on micro-organisms. Furthermore, Beraha et al. (1960) reported that multicellular-spored fungi (Alternaria and Rhizopus) have greater resistance to gamma radiation than monocellular-spored fungi (Penicillium). It was also stated that even species within the same genera show a different resistance-ability to gamma radiation.

Enzyme systems are inactivated by both direct and indirect action of radiation. Barron (1952) found that all enzymes containing SH groups are readily inactivated, and suggested that this inactivation

was due to the oxidation of the SH groups by hydroxyl radicals.

$$2\text{-SH} + 2\ OH\cdot \longrightarrow \text{-S-S-} + 2H_2O\cdot$$

This supposition has been supported by the observation that inactivation is increased by the presence of oxygen:

$$2\text{-SH} + 2HO_2 \longrightarrow \text{-S-S} + 2H_2O_2$$

$$2\text{-SH} + H_2O_2 \longrightarrow \text{-S-S} + 2\ H_2O.$$

Along with these above-stated reactions, probably many more occur simultaneously. Therefore, this disturbance of the enzyme systems caused by the radiation probably changes the normal physiological processes of biological materials and especially the respiration processes of the living organisms such as fruits and vegetables.

SUMMARY AND CONCLUSIONS

This research was conducted in 1960 and 1961 to study the effects of selected fungicides, antibiotics, beta and gamma radiations, and packaging films on respiration, control of fungal deteriorations, and subsequent refrigeration life of apricots, peaches, and pears. Also, the fungi responsible for deterioration of these fruits were studied in vitro to determine if they were susceptible or resistant to selected chemicals and ionizing (beta and gamma) radiations.

Respiratory behavior of the fruits under normal as well as modified conditions were assessed with a Claypool and Keefer-type respirometer and Orsat-type gas analyzer, respectively. Two kinds of films, namely Duratite and polyethylene, were used for packaging fruits. The fruits after treatments and packaging were stored for the entire length of their storage period at 40° F and 85 percent relative humidity and at 75° F and 35 percent relative humidity.

Effects of Chemical Treatments

Apricots (vars. Large Early Montgamet and Moorpark)

From the chemical effects studied on apricots (var. Large Early Montgamet), it seemed that Dowicide-A had delayed the climacteric rise by 4 days while sorbic acid and Mycostatin had advanced the climacteric by 2 days. With the apricots (var. Moorpark), Dowicide-A and sorbic acid delayed the climacteric by 4 days and 2 days, respectively, but Captan and Mycostatin advanced it by 8 days and by 2 days, respectively. Therefore, it was concluded that the varieties behaved differently to

the chemical treatments applied.

Peaches (var. Elberta)

The study on peaches (var. Elberta) was conducted at 40° F and 85 percent relative humidity and at 75° F and 35 percent relative humidity. The climacteric rise of peaches, regardless of the treatments, was much faster than that of apricots. The climacteric rise was delayed by 2 days with Dowicide-A treatment and by 4 days with sorbic acid treatment, whereas Mycostatin treatment advanced the climacteric point 6 days earlier than the control. At 75° F, fruit respired much faster and higher than the fruit at 40° F. The climacteric in the case of all treatments, including the nontreated controls, was reached on the same day.

The study of fungi *in vitro* was conducted at 40° F and 85 percent relative humidity and at 75° F and 35 percent relative humidity. Captan at both concentrations was by far the most effective in inhibiting the growth of fungi, whereas other chemicals in their descending order of effectiveness were Mycostatin, Dowicide-A, and sorbic acid. This sequence of the inhibiting effect of the chemicals on fungus growth was similar to that observed *in vivo*.

Effects of Chemical Treatments and Packaging Films

Apricots (vars. Large Early Montgamet and Moorpark)

Experiments with packaging films showed that, in general, regardless of chemical treatments, both apricot varieties maintained higher O_2 and lower CO_2 contents in atmospheres inside polyethylene film for longer periods of time than in atmospheres inside Duratite film.

Apricots with Captan and Mycostatin treatments, regardless of the films used, maintained lower levels of CO_2 than Dowicide-A and sorbic acid. The chemical treatments and packaging films which maintained lower levels of CO_2 and higher levels of O_2 around the apricot fruit were better in keeping the apricots for longer periods of time than other treatment and packaging film combinations which maintained higher levels of CO_2 and lower levels of O_2.

Because of its softer nature, the Moorpark variety deteriorated earlier than Large Early Montgamet, which was firmer. Furthermore, Moorpark apricots deteriorated earlier inside Duratite film, regardless of the treatments, because of higher levels of CO_2 than in polyethylene film. The micro-organisms which were responsible for the apricot fruit deterioration were mainly Penicillium and Rhizopus species.

Peaches (var. Elberta)

The peaches (var. Elberta) were treated with chemicals and then packaged in Duratite and polyethylene films. The treated and packaged fruit was stored at 40° F and 85 percent relative humidity for 39 days. It was observed that in general, regardless of the chemical treatments, polyethylene film maintained lower levels of CO_2 and higher O_2 than Duratite film. The chemical treatments with Captan and Mycostatin, regardless of the films used, maintained lower levels of CO_2 than Dowicide-A and sorbic acid treatments. There was not much difference between the chemical concentrations in maintaining the levels of the above-mentioned gases with any of the film and chemical combinations.

The evaluation of marketable quality of the fruit showed that Captan was the best treatment in inhibiting fungus growth on the fruit. Increased concentration of each chemical had little or no significant

effect in preventing spoilage. The organisms responsible for spoilage were predominantly Penicillium and Rhizopus species.

Pears (var. Bartlett)

After the chemical treatments, pears were packaged in Duratite film and stored at 40° F and 85 percent relative humidity. It was found that the respiration rate of pears was slower than that of apricots and peaches. Higher concentrations of chemical treatments maintained lower levels of CO_2 inside Duratite film than the same treatments at lower chemical concentrations. Sorbic acid treatments maintained higher levels of CO_2 inside Duratite film than Captan, Mycostatin, and controls. Certain chemical treatments such as Captan and Mycostatin helped to control the internal breakdown of pears in combination with Duratite film, maintaining modified atmospheres at 40° F. Captan and Mycostatin were better in protecting the fruits from fungus infestations than Dowicide-A and sorbic acid. The organism responsible for the spoilage of pears was predominantly a Penicillium species.

Effects of Ionizing Radiations

Peaches (vars. Elberta and Gem)

Beta radiation dosages to peaches at 1×10^5, 3×10^5, and 5×10^5 rads delayed the climacteric rise by 4, 18, and 14 days, respectively, whereas in case of gamma radiation dosages 1×10^5 and 3×10^5 rads delayed the climacteric by 2 days and by 10 days, respectively. A fungus study in vitro was conducted at ambient (75° F) temperature and relative humidity (35 percent). The results obtained with beta radiation showed that the fungus inhibition effect of radiation was directly

proportional to the dosage applied.

Effects of Ionizing Radiations and Packaging Films

Peaches (vars. Elberta and Gem)

Peaches (var. Elberta) were packaged in Duratite film and then were irradiated with beta rays, while peaches (var. Gem) were irradiated with gamma rays before they were packaged in Duratite and polyethylene films. In beta radiation experiments the CO_2 accumulation inside the Duratite bags increased with the increasing radiation dosages; whereas in gamma radiation, dosages applied behaved similarly for both the films except that the levels of CO_2 maintained in polyethylene film were lower than in Duratite film. At radiation dosage of 5×10^5 rads, injuries on peaches (var. Gem) were shown as black areas on the surface of the fruit.

Beta radiation dosages of 1×10^5 and 3×10^5 rads proved to be effective in controlling fungus growth and keeping fruit for longer periods of time than in the controls and the 5×10^5 rads treatment. The evaluation of marketable quality of the fruit in gamma radiation experiments was similar to that obtained with beta radiation with the exception that the gamma radiation dosage of 3×10^5 rads was best in controlling spoilage by fungi while the beta radiation treatment of 1×10^5 rads was the best protective dosage. In general, fruits packaged in polyethylene seemed to be better protected than fruits packaged in Duratite bags. The fungi observed on peaches were predominantly Penicillium and Rhizopus species.

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APPENDIX

Table 11. Analyses of variance for the effects of chemical treatments on the production of CO_2 from (a) apricots (var. Large Early Montgamet); (b) apricots (var. Moorpark), both stored at 40° F and 85 percent relative humidity; (c) peaches (var. Elberta) stored at 40° F and 85 percent relative humidity; and (d) peaches (var. Elberta) stored at 75° F and 30 percent relative humidity for several days (1960)

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[a]
(for apricots var. Large Early Montgamet at 40° F)					
Observation interval	19	8506.56	447.71	7.73	**
Chemical	4	960.97	240.24	4.15	**
Error	76	4402.27	57.92		
Total	99	13869.80			
(for apricots var. Moorpark at 40° F)					
Observation interval	19	12005.70	631.88	12.15	**
Chemical	4	516.62	129.15	2.48	*
Error	76	3952.43	52.00		
Total	99	16474.75			
(for peaches var. Elberta at 40° F)					
Observation interval	13	5794.74	445.75	11.36	**
Chemical	4	186.34	46.58	1.19	NS
Error	52	2039.66	39.22		
Total	69	8029.74			
(for peaches var. Elberta at 75° F)					
Observation interval	5	8701.91	1740.38	13.62	**
Chemical	4	2666.82	666.70	5.22	**
Error	20	2555.87	127.79		
Total	29	13924.60			

[a] * = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.

Table 12. Analyses of variance for effects of chemical treatments on the production of CO_2 from (a) apricots (var. Large Early Montgamet) and (b) peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for several days (1961)

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[a]
(for apricots var. Large Early Montgamet)					
Observation interval	9	545.45	60.60	20.40	**
Chemical	4	192.11	48.03	16.17	**
Error	36	106.78	2.97		
Total	49	844.34			
(for peaches var. Elberta)					
Observation interval	14	3470.63	247.90	4.16	**
Chemical	4	64.42	16.10	0.27	NS
Error	56	3334.11	59.54		
Total	74	6969.16			

[a] ** = significant at 1 percent level. NS = not significant at 5 percent level.

Table 12a. Analyses of variance for effects of gamma and beta radiations on the production of CO_2 from (a) peaches (var. Elberta) irradiated with beta rays; and (b) peaches (var. Gem) irradiated with Gamma rays, stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[a]
(for peaches var. Elberta)					
Observation interval	14	1293.30	92.38	2.11	*
Dosage	3	357.45	119.15	2.72	NS
Error	42	1841.28	43.84		
Total	59	3492.03			
(for peaches var. Gem)					
Observation interval	7	178.11	25.44	1.48	NS
Dosage	3	893.38	297.79	17.31	**
Error	21	361.23	17.20		
Total	31	1432.72			

[a]* = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.

Table 13. Analysis of variance for effects of chemical treatments and packaging films on the production of CO_2 from apricots (var. Large Early Montgamet) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	378.67	31.55	67.13	**
Error (a)	26	12.14	0.47		
Film	1	125.80	125.80	331.05	**
F x O	12	39.13	3.26	8.58	**
Error (b)	26	9.99	0.38		
Chemical	4	62.17	15.54	31.71	**
C x O	48	40.24	0.84	1.71	**
C x F	4	27.71	6.93	14.14	**
C x F x O	48	16.90	0.35	0.71	NS
Error (c)	208	101.18	0.49		
Total	389	813.91			

[a] F = film. O = observation interval. C = chemical.
[b] ** = significant at 1 percent level. NS - not significant at 5 percent level.

Table 13a. Analysis of variance for effects of chemical treatments and packaging films on O_2 uptake by apricots (var. Large Early Montgamet) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	3660.88	305.07	246.02	**
Error (a)	26	32.19	1.24		
Film	1	167.91	167.91	202.03	**
F x O	12	111.30	9.27	11.16	**
Error (b)	26	21.61	0.83		
Chemical	4	48.28	12.07	15.88	**
C x O	48	70.50	1.47	1.93	**
C x F	4	11.50	2.87	3.78	**
C x F x O	48	62.88	1.31	1.72	**
Error (c)	208	159.23	0.76		
Total	389	4346.28			

[a] F = film. O = observation interval. C = chemical.
[b] ** = significant at 1 percent level.

Table 14. Analysis of variance for effects of chemical treatments and packaging films on the production of CO_2 from apricots (var. Moorpark) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	366.34	30.53	105.27	**
Error (a)	26	7.44	0.29		
Film	1	202.46	202.46	595.47	**
F x O	12	17.91	1.49	4.38	**
Error (b)	26	8.99	0.34		
Chemical	4	25.31	6.33	17.58	**
C x O	48	27.52	0.57	1.58	*
C x F	4	14.82	3.70	10.28	**
C x F x O	48	15.24	0.32	0.89	NS
Error (c)	208	74.59	0.36		
Total	389	760.62			

[a] F = film. O = observation interval. C = chemical.
[b] * = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.

Table 14a. Analysis of variance for effects of chemical treatments and packaging films on O_2 uptake by apricots (var. Moorpark) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	4275.80	356.32	342.61	**
Error (a)	26	26.96	1.04		
Film	1	125.69	125.69	74.81	**
F x O	12	67.66	5.64	3.36	**
Error (b)	26	43.67	1.68		
Chemical	4	8.47	2.12	3.31	*
C x O	48	37.18	0.77	1.20	NS
C x F	4	10.64	2.66	4.16	**
C x F x O	48	31.32	0.65	1.01	NS
Error (c)	208	132.89	0.64		
Total	389	4760.28			

[a] F = film. O = observation interval. C = chemical.
[b] * = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.

Table 15. Chi-square analysis for effects of chemical treatments and Duratite packaging film on marketable fruits of peaches (var. Elberta) inoculated with fungi (Penicillium, Rhizopus, Alternaria, and Monilinia species) prior to the treatments and packaging and then stored at 40° F and 85 percent relative humidity for 40 days (observations taken at 20, 30, and 40 days intervals, 1960)

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
For Concentration One[b]				
After 20 days of storage:				
Among chemicals	4	0.62	122.41	**
Comparison between Captan and Control	1	0.50	90.00	**
Comparison between Mycostatin and Control	1	0.40	60.00	**
Comparison between Dowicide-A and Control	1	0.43	70.42	**
Comparison between Sorbic acid and Control	1	0.22	27.78	**
Comparison between Captan and Mycostatin	1	0.90	10.00	**
Comparison between Captan and Dowicide-A	1	0.93	4.44	*
Comparison between Captan and Sorbic acid	1	0.72	33.07	**
Comparison between Mycostatin and Dowicide-A	1	0.83	0.62	NS
Comparison between Mycostatin and Sorbic acid	1	0.62	11.85	**
Comparison between Dowicide-A and Sorbic acid	1	0.65	16.71	**
After 30 days of storage:				
Among chemicals	4	0.22	152.05	**
Comparison between Captan and Control	1	0.43	70.42	**
Comparison between Mycostatin and Control	1	0.08	7.42	**
Comparison between Dowicide-A and Control	1	0.02	2.50	NS
Comparison between Sorbic acid and Control	1	0.01	1.25	NS
Comparison between Captan and Mycostatin	1	0.51	45.51	**

Table 15. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between Captan and Dowicide-A	1	0.45	63.80	**
Comparison between Captan and Sorbic acid	1	0.44	66.85	**
Comparison between Nycostatin and Dowicide-A	1	0.10	3.09	NS
Comparison between Nycostatin and Sorbic acid	1	0.09	5.44	*
Comparison between Dowicide-A and Sorbic acid	1	0.03	0.38	NS
After 40 days of storage:				
Among chemicals	4	0.14	222.02	**
Comparison between Captan and Control	1	0.33	47.62	**
Comparison between Nycostatin and Control	1	0.02	1.16	NS
Comparison between Dowicide-A and Control	1	0.00	0.00	NS
Comparison between Sorbic acid and Control	1	0.00	0.00	NS
Comparison between Captan and Nycostatin	1	0.35	951.53	**
Comparison between Captan and Dowicide-A	1	0.33	47.62	**
Comparison between Captan and Sorbic acid	1	0.33	47.62	**
Comparison between Nycostatin and Dowicide-A	1	0.02	1.16	NS
Comparison between Nycostatin and Sorbic acid	1	0.02	1.16	NS
Comparison between Dowicide-A and Sorbic acid	1	0.00	0.00	NS
Among observation intervals within Captan	2	0.84	15.83	**
Among observation intervals with Nycostatin	2	0.33	71.32	**
Among observation intervals within Dowicide-A	2	0.30	102.08	**
Among observation intervals within Sorbic acid	2	0.15	87.41	**
Among observation intervals within Control	2	0.00	0.00	NS

Table 15. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
For Concentration Two[c]				
After 20 days of storage:				
Among chemicals	4	0.66	139.00	**
Comparison between Captan and Control	1	0.50	90.00	**
Comparison between Mycostatin and Control	1	0.43	70.42	**
Comparison between Dowicide-A and Control	1	0.49	86.04	**
Comparison between Sorbic acid and Control	1	0.22	27.78	**
Comparison between Captan and Mycostatin	1	0.93	4.44	*
Comparison between Captan and Dowicide-A	1	0.99	0.12	NS
Comparison between Captan and Sorbic acid	1	0.72	33.07	**
Comparison between Mycostatin and Dowicide-A	1	0.92	3.09	NS
Comparison between Mycostatin and Sorbic acid	1	0.65	16.71	**
Comparison between Dowicide-A and Sorbic acid	1	0.71	30.47	**
After 30 days of storage:				
Among chemicals	4	0.17	53.44	**
Comparison between Captan and Control	1	0.50	90.00	**
Comparison between Mycostatin and Control	1	0.80	8.39	**
Comparison between Dowicide-A and Control	1	0.98	9.67	**
Comparison between Sorbic acid and Control	1	0.00	0.00	NS
Comparison between Captan and Mycostatin	1	0.34	15.29	**
Comparison between Captan and Dowicide-A	1	0.35	13.54	**
Comparison between Captan and Sorbic acid	1	0.27	30.48	**

Table 15. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between Mycostatin and Dowicide-A	1	0.17	0.07	NS
Comparison between Mycostatin and Sorbic acid	1	0.08	8.39	**
Comparison between Dowicide-A and Sorbic acid	1	0.09	9.67	**
After 40 days of storage:				
Among chemicals	4	0.13	139.46	**
Comparison between Captan and Control	1	0.30	38.57	**
Comparison between Mycostatin and Control	1	0.02	2.27	NS
Comparison between Dowicide-A and Control	1	0.00	0.00	NS
Comparison between Sorbic acid and Control	1	0.00	0.00	NS
Comparison between Captan and Mycostatin	1	0.32	33.07	**
Comparison between Captan and Dowicide-A	1	0.30	38.57	**
Comparison between Captan and Sorbic acid	1	0.30	38.57	**
Comparison between Mycostatin and Dowicide-A	1	0.02	2.27	NS
Comparison between Mycostatin and Sorbic acid	1	0.02	2.27	NS
Comparison between Dowicide-A and Sorbic acid	1	0.00	0.00	NS
Among observation intervals within Captan	2	0.71	27.30	**
Among observation intervals within Mycostatin	2	0.35	85.29	**
Among observation intervals within Dowicide-A	2	0.38	101.73	**
Among observation intervals within Sorbic acid	2	0.15	65.85	**
Among observation intervals within Control	2	0.00	0.00	NS

Table 15. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between Chemical Concentrations				
After 20 days of storage:				
Captan 1200 ppm and 2400 ppm	1	0.00	0.00	NS
Mycostatin 100 ppm and 200 ppm	1	0.83	0.62	NS
Dowicide-A 1000 ppm and 2000 ppm	1	0.92	3.09	NS
Sorbic acid 5000 ppm and 10,000 ppm	1	0.44	0.00	NS
After 30 days of storage:				
Captan 1200 ppm and 2400 ppm	1	0.70	11.90	**
Mycostatin 100 ppm and 200 ppm	1	0.15	0.00	NS
Dowicide-A 1000 ppm and 2000 ppm	1	0.11	4.44	*
Sorbic acid 5000 ppm and 10,000 ppm	1	0.01	1.14	NS
After 40 days of storage:				
Captan 1200 ppm and 2400 ppm	1	0.63	0.42	NS
Mycostatin 100 ppm and 200 ppm	1	0.04	0.00	NS
Dowicide-A 1000 ppm and 2000 ppm	1	0.00	0.00	NS
Sorbic acid 5000 ppm and 10,000 ppm	1	0.00	0.00	NS

[a] * = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.

[b] Captan 1200 ppm; Mycostatin 100 ppm; Dowicide-A 1000 ppm; and Sorbic acid 5000 ppm.

[c] Captan 2400 ppm; Mycostatin 200 ppm; Dowicide-A 2000 ppm; and Sorbic acid 10,000 ppm.

Table 16. Analysis of variance for effects of chemical treatments and packaging films on the production of CO_2 from peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	19	16480.70	867.40	12391.43	**
Error (a)	40	3.03	0.07		
Film	1	2114.28	2114.28	42285.60	**
F x O	19	167.47	8.81	176.20	**
Error (b)	40	2.20	0.05		
Chemical	8	196.56	24.57	491.40	**
C x O	152	725.78	4.77	95.40	**
C x F	8	502.67	62.83	1256.60	**
C x F x O	152	851.09	5.60	112.00	**
Error (c)	640	30.17	0.05		
Total	1079	21073.95			

[a]F = film. O = observation interval. C = chemical.
[b]** = significant at 1 percent level.

Table 16a. Analysis of variance for effects of chemical treatments and packaging films on O_2 uptake by peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	19	2587.27	136.18	2239.67	**
Error (a)	40	2.43	0.06		
Film	1	88.64	88.64	2278.59	**
F x O	19	224.36	11.81	303.56	**
Error (b)	40	1.56	0.04		
Chemical	8	178.67	22.33	516.98	**
C x O	152	376.50	2.48	57.34	**
C x F	8	234.91	29.36	579.11	**
C x F x O	152	232.19	1.53	35.36	**
Error (c)	640	27.68	0.04		
Total	1079	3954.21			

[a]F = film. O = observation interval. C = chemical.
[b]** = significant at 1 percent level.

Table 17. Chi-square analysis for effects of chemical treatments and Duratite packaging film on marketable fruits of pears (var. Bartlett) inoculated with fungi (Penicillium, Rhizopus, Alternaria, and Monilinia species) prior to the treatments and packaging and then stored at 40° F and 85 percent relative humidity for 60 days (observations taken at 30, 45, and 60 days intervals, 1960)

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
For Concentration One[b]				
After 30 days of storage:				
Among chemicals	4	0.89	32.79	**
Comparison between Captan and Control	1	0.80	10.00	**
Comparison between Mycostatin and Control	1	0.81	10.35	**
Comparison between Dowicide-A and Control	1	0.82	13.61	**
Comparison between Sorbic acid and Control	1	0.80	10.00	**
Comparison between Captan and Mycostatin	1	0.94	0.12	NS
Comparison between Captan and Dowicide-A	1	0.95	0.49	NS
Comparison between Captan and Sorbic acid	1	0.93	0.00	NS
Comparison between Mycostatin and Dowicide-A	1	0.97	0.25	NS
Comparison between Mycostatin and Sorbic acid	1	0.94	0.12	NS
Comparison between Dowicide-A and Sorbic Acid	1	0.95	0.49	NS
After 45 days of storage:				
Among chemicals	4	0.73	76.69	**
Comparison between Captan and Control	1	0.51	34.84	**
Comparison between Mycostatin and Control	1	0.57	50.42	**
Comparison between Dowicide-A and Control	1	0.53	40.00	**
Comparison between Sorbic acid and Control	1	0.51	34.84	**

Table 17. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between Captan and Mycostatin	1	0.88	3.09	NS
Comparison between Captan and Dowicide-A	1	0.84	2.78	NS
Comparison between Captan and Sorbic acid	1	0.82	0.00	NS
Comparison between Mycostatin and Dowicide-A	1	0.90	1.11	NS
Comparison between Mycostatin and Sorbic acid	1	0.88	3.09	NS
Comparison between Dowicide-A and Sorbic acid	1	0.84	0.28	NS
After 60 days of storage:				
Among chemicals	4	0.32	40.13	**
Comparison between Captan and Control	1	0.20	22.50	**
Comparison between Mycostatin and Control	1	0.29	35.77	**
Comparison between Dowicide-A and Control	1	0.20	22.50	**
Comparison between Sorbic acid and Control	1	0.12	14.94	**
Comparison between Captan and Mycostatin	1	0.49	2.84	NS
Comparison between Captan and Dowicide-A	1	0.40	0.00	NS
Comparison between Captan and Sorbic acid	1	0.32	2.59	NS
Comparison between Cycostatin and Dowicide-A	1	0.49	2.84	NS
Comparison between Mycostatin and Sorbic acid	1	0.41	10.42	**
Comparison between Dowicide-A and Sorbic acid	1	0.32	2.59	NS
Among observation intervals within Captan	2	0.72	33.94	**
Among observation intervals with Mycostatin	2	0.82	25.28	**
Among observation intervals within Dowicide-A	2	0.75	40.28	**

Table 17. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Among observation intervals within Sorbic acid	2	0.67	58.62	**
Among observation intervals within Control	2	0.29	50.16	**
For Concentration Two[c]				
After 30 days of storage:				
Among chemicals	4	0.90	33.88	**
Comparison between Captan and Control	1	0.81	10.35	**
Comparison between Mycostatin and Control	1	0.81	10.35	**
Comparison between Dowicide-A and Control	1	0.82	13.61	**
Comparison between Sorbic acid and Control	1	0.80	10.00	**
Comparison between Captan and Mycostatin	1	0.95	0.00	NS
Comparison between Captan and Dowicide-A	1	0.97	0.25	NS
Comparison between Captan and Sorbic acid	1	0.94	0.12	NS
Comparison between Mycostatin and Dowicide-A	1	0.97	0.25	NS
Comparison between Mycostatin and Sorbic acid	1	0.94	0.12	NS
Comparison between Dowicide-A and Sorbic acid	1	0.95	0.49	NS
After 45 days of storage:				
Among chemicals	4	0.75	82.24	**
Comparison between Captan and Control	1	0.57	50.42	**
Comparison between Mycostatin and Control	1	0.57	50.42	**
Comparison between Dowicide-A and Control	1	0.51	34.84	**
Comparison between Sorbic acid and Control	1	0.52	37.38	**
Comparison between Captan and Mycostatin	1	0.93	0.00	NS

Table 17. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between Captan and Dowicide-A	1	0.88	3.86	*
Comparison between Captan and Sorbic acid	1	0.89	1.97	NS
Comparison between Mycostatin and Dowicide-A	1	0.88	3.08	NS
Comparison between Mycostatin and Sorbic acid	1	0.89	1.97	NS
Comparison between Dowicide-A and Sorbic acid	1	0.83	0.07	NS
After 60 days of storage:				
Among chemicals	4	0.36	37.11	**
Comparison between Captan and Control	1	0.29	35.77	**
Comparison between Mycostatin and Control	1	0.15	24.19	**
Comparison between Dowicide-A and Control	1	0.23	30.62	**
Comparison between Sorbic acid and Control	1	0.22	27.78	**
Comparison between Captan and Mycostatin	1	0.44	6.67	**
Comparison between Captan and Dowicide-A	1	0.52	1.11	NS
Comparison between Captan and Sorbic acid	1	0.51	1.60	NS
Comparison between Mycostatin and Dowicide-A	1	0.39	2.27	NS
Comparison between Mycostatin and Sorbic acid	1	0.38	1.67	NS
Comparison between Dowicide-A and Sorbic acid	1	0.45	0.05	NS
Among observation intervals within Captan	2	0.82	25.28	**
Among observation intervals within Mycostatin	2	0.73	57.35	**
Among observation intervals within Dowicide-A	2	0.75	29.42	**
Among observation intervals within Sorbic acid	2	0.74	29.07	**
Among observation intervals within Control	2	0.29	50.16	**

Table 17. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between chemical concentrations				
After 30 days of storage:				
Captan 1200 ppm and 2400 ppm	1	0.94	0.12	NS
Mycostatin 100 ppm and 200 ppm	1	0.95	0.00	NS
Dowicide-A 1000 ppm and 2000 ppm	1	0.97	0.00	NS
Sorbic acid 5000 ppm and 10,000 ppm	1	0.93	0.00	NS
After 45 days of storage:				
Captan 1200 ppm and 2400 ppm	1	0.88	3.09	NS
Mycostatin 100 ppm and 200 ppm	1	0.93	0.00	NS
Dowicide-A 1000 ppm and 2000 ppm	1	0.84	0.28	NS
Sorbic acid 5000 ppm and 10,000 ppm	1	0.83	0.07	NS
After 60 days of storage:				
Captan 1200 ppm and 2400 ppm	1	0.49	2.84	NS
Mycostatin 100 ppm and 200 ppm	1	0.44	6.67	**
Dowicide-A 1000 ppm and 2000 ppm	1	0.43	0.42	NS
Sorbic acid 5000 ppm and 10,000 ppm	1	0.34	4.28	*

[a]* = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.

[b]Captan 1200 ppm; Mycostatin 100 ppm; Dowicide-A 1000 ppm; and Sorbic acid 5000 ppm.

[c]Captan 2400 ppm; Mycostatin 200 ppm; Dowicide-A 2000 ppm; Sorbic acid 10,000 ppm.

Table 18. Analysis of variance for effect of chemical treatments and Duratite packaging film on the production of CO_2 from pears (var. Bartlett) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	24	1923.30	80.14	890.44	**
Error (a)	50	4.63	0.09		
Chemical	6	86.66	14.44	288.80	**
C x O	144	94.36	0.65	13.00	**
Error (b)	300	15.24	0.05		
Total	524	2124.19			

[a] C = chemical. O = observation interval.
[b] ** = significant at 1 percent level.

Table 18a. Analysis of variance for effects of chemical treatments and Duratite packaging film on O_2 uptake by pears (var. Bartlett) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	24	4057.91	169.08	1690.80	**
Error (a)	50	4.98	0.10		
Chemical	6	22.90	3.82	16.61	**
C x O	144	75.99	0.53	2.30	**
Error (b)	300	68.62	0.23		
Total	524	4230.40			

[a] C = chemical. O = observation interval.
[b] ** = significant at 1 percent level.

Table 18b. Analysis of variance for effects of chemical treatments and Duratite packaging film on the production of CO_2 from pears (var. Bartlett) stored at 40° F and 85 percent relative humidity for several days (1961)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	298.01	24.83	413.83	**
Error (a)	13	0.74	0.06		
Chemical	4	7.47	1.87	93.50	**
C x O	48	11.74	0.24	12.00	**
Error (b)	52	1.34	0.02		
Total	129	319.30			

[a] C = chemical. O = observation interval.
[b] ** = significant at 1 percent level.

Table 18c. Analysis of variance for effects of chemical treatments and Duratite packaging film on O_2 uptake by pears (var. Bartlett) stored at 40° F and 85 percent relative humidity for several days (1961)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	1307.52	108.96	5448.00	**
Error (a)	13	0.30	0.02		
Chemical	4	0.91	0.23	11.50	**
C x O	48	20.73	0.43	21.50	**
Error (b)	52	0.90	0.02		
Total	129	1330.36			

[a] C = chemical. O - observation interval.
[b] ** = significant at 1 percent level.

Table 19. Chi-square analysis for effects of beta radiation and Duratite packaging film on marketable fruits of peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for 50 days (observations taken at 30, 40, and 50 days intervals, 1960)

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
After 30 days of storage:				
Among radiation dosages[b]	3	0.96	2.52	NS
Comparison between 1 x 10^5 r and Control	1	0.00	0.00	NS
Comparison between 3 x 10^5 r and Control	1	0.97	0.74	NS
Comparison between 5 x 10^5 r and Control	1	0.95	1.67	NS
Comparison between 1 x 10^5 r and 5 x 10^5 r	1	0.95	1.67	NS
Comparison between 1 x 10^5 r and 3 x 10^5 r	1	0.97	0.74	NS
Comparison between 3 x 10^5 r and 5 x 10^5 r	1	0.92	0.18	NS
After 40 days of storage:				
Among radiation dosages	3	0.63	22.78	**
Comparison between 1 x 10^5 r and Control	1	0.80	6.67	**
Comparison between 3 x 10^5 r and Control	1	0.77	10.42	**
Comparison between 5 x 10^5 r and Control	1	0.63	22.50	**
Comparison between 1 x 10^5 r and 5 x 10^5 r	1	0.50	6.94	**
Comparison between 1 x 10^5 r and 3 x 10^5 r	1	0.63	0.28	NS
Comparison between 3 x 10^5 r and 5 x 10^5 r	1	0.47	4.27	*
After 50 days of storage:				
Among radiation dosages	3	0.24	51.42	**
Comparison between 1 x 10^5 r and Control	1	0.40	22.50	**
Comparison between 3 x 10^5 r and Control	1	0.42	20.07	**

Table 19. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between 5×10^5 r and Control	1	0.37	27.78	**
Comparison between 1×10^5 r and 5×10^5 r	1	0.07	1.02	NS
Comparison between 1×10^5 r and 3×10^5 r	1	0.12	0.18	NS
Comparison between 3×10^5 r and 5×10^5 r	1	0.08	2.04	NS
Among observation intervals within 1×10^5 r	2	0.59	51.76	**
Among observation intervals within 3×10^5 r	2	0.55	38.76	**
Among observation intervals within 5×10^5 r	2	0.42	48.43	**
Among observation intervals within Control	2	0.88	16.55	**

[a] * = significant at 5 percent level. ** = significant at 1 percent level. NS - not significant at 5 percent level.

[b] r = rad.

Table 20. Analysis of variance for effects of beta radiation and Duratite packaging film on the production of CO_2 from peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	16	483.49	30.22	755.50	**
Error (a)	34	1.31	0.04		
Chemical	3	28.41	9.47	157.83	**
C x O	48	34.77	0.72	12.00	**
Error (b)	102	6.39	0.06		
Total	203	554.37			

[a] C = chemical. O = observation interval.
[b] ** = significant at 1 percent level.

Table 20a. Analysis of variance for effects of beta radiation and Duratite packaging film on O_2 uptake by peaches (var. Elberta) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	16	1208.57	75.53	343.32	**
Error (a)	34	7.38	0.22		
Chemical	3	120.77	40.26	118.41	**
C x O	48	64.86	1.35	3.97	**
Error (b)	102	35.24	0.34		
Total	203	1436.82			

[a] C = chemical. O = observation interval.
[b] ** = significant at 1 percent level.

Table 21. Chi-square analysis for effects of gamma radiation and polyethylene packaging film on marketable fruits of peaches (var. Gem) stored at 40° F and 85 percent relative humidity for 40 days (observations taken at 20, 30, and 40 days intervals, 1960)

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
After 20 days of storage:				
Among radiation dosages	3	0.97	7.82	*
Comparison between 1 x 10^5 r and Control	1	0.00	0.00	NS
Comparison between 3 x 10^5 r and Control	1	0.00	0.00	NS
Comparison between 5 x 10^5 r and Control	1	0.95	1.67	NS
Comparison between 1 x 10^5 r and 5 x 10^5 r	1	0.95	1.67	NS
Comparison between 1 x 10^5 r and 3 x 10^5 r	1	0.00	0.00	NS
Comparison between 3 x 10^5 r and 5 x 10^5 r	1	0.95	1.67	NS
After 30 days of storage:				
Among radiation dosages	3	0.78	11.87	**
Comparison between 1 x 10^5 r and Control	1	0.75	1.98	NS
Comparison between 3 x 10^5 r and Control	1	0.82	8.64	**
Comparison between 5 x 10^5 r and Control	1	0.67	0.00	NS
Comparison between 1 x 10^5 r and 5 x 10^5 r	1	0.75	1.98	NS
Comparison between 1 x 10^5 r and 3 x 10^5 r	1	0.90	2.96	NS
Comparison between 3 x 10^5 r and 5 x 10^5 r	1	0.82	8.64	**
After 40 days of storage:				
Among radiation dosages	3	0.46	23.29	**
Comparison between 1 x 10^5 r and Control	1	0.40	2.50	NS
Comparison between 3 x 10^5 r and Control	1	0.55	15.00	**
Comparison between 5 x 10^5 r and Control	1	0.27	0.32	NS

Table 21. Continued

Source of variation	Degrees of freedom	Probability of success	Chi-square	Level of significance[a]
Comparison between 1 x 10^5 r and 5 x 10^5 r	1	0.37	4.44	*
Comparison between 1 x 10^5 r and 3 x 10^5 r	1	0.65	5.62	*
Comparison between 3 x 10^5 r and 5 x 10^5 r	1	0.52	19.27	**
Among observation intervals within 1 x 10^5 r	2	0.78	24.31	**
Among observation intervals within 3 x 10^5 r	2	0.92	7.66	*
Among observation intervals within 5 x 10^5 r	2	0.60	28.61	**
Among observation intervals within Control	2	0.65	30.65	**

[a] * = significant at 5 percent level. ** = significant at 1 percent level. NS = not significant at 5 percent level.
[b] r = rad.

Table 22. Analysis of variance for effects of gamma radiation and packaging films for the production of CO_2 from peaches (var. Gem) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	1106.51	92.21	3073.67	**
Error (a)	26	0.70	0.03		
Film	1	906.45	906.45	18129.00	**
F x O	12	103.19	8.60	172.00	**
Error (b)	26	1.34	0.05		
Chemical	3	133.36	44.45	493.89	**
C x O	36	148.32	4.12	45.78	**
C x F	3	338.81	112.94	1254.89	**
C x F x O	36	82.71	2.30	25.55	**
Error (c)	156	14.68	0.09		
Total	311	2836.07			

[a] F = film. O = observation interval. C = chemical.
[b] ** = significant at 1 percent level.

Table 22a. Analysis of variance for effects of gamma radiation and packaging films on O_2 uptake by peaches (var. Gem) stored at 40° F and 85 percent relative humidity for several days (1960)

Source of variation[a]	Degrees of freedom	Sum of squares	Mean squares	F value	Level of significance[b]
Observation interval	12	120.94	10.08	168.00	**
Error (a)	26	1.55	0.06		
Film	1	622.21	622.21	12444.20	**
F x O	12	29.06	2.42	48.40	**
Error (b)	26	1.33	0.05		
Chemical	3	14.35	4.78	79.67	**
C x O	36	63.23	1.76	29.33	**
C x F	3	95.98	31.99	533.17	**
C x F x O	36	39.35	1.09	18.17	**
Error (c)	156	9.26	0.06		
Total	311	997.26			

[a] F = film. O = observation interval. C = chemical.
[b] ** = significant at 1 percent level.